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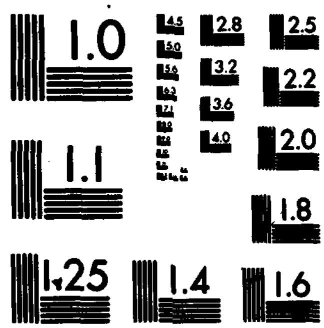

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A comprehensive study of current bridge design practice was carried out in order to determine the criteria for selection of appropriate applications software. The study provided the basis for establishing fundamental selection criteria for the evaluation of existing bridge design software. Using the criteria, 204 existing programs (and systems) were evaluated for potential use in the prototype system. From this initial group,

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20. ABSTRACT (Continued)

twelve programs in four general application areas (superstructure, geometry, substructures, and piles) were selected as most likely candidates for universal usage. As a product of this evaluation, abstracts of all 204 programs were compiled which include a features discription of each program.

This report was prepared as part of efforts under the Computer-Aided Structural Engineering (CASE) Project.

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PREFACE

This report summarizes findings of a National Cooperative Highway Research Program (NCHRP) study on available highway bridge computer programs. The report was prepared by Dr. David R. Schelling for the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., under Contract No. DACW39-78-M-5127.

The research on which this report is based was performed by Multisystems, Incorporated, of Cambridge, Mass., and by the Department of Civil Engineering, University of Maryland, and the School of Civil Engineering, Georgia Institute of Technology, under subcontracts to Multisystems.

The reporting was part of efforts under the Computer-Aided Structural Engineering (CASE) Project funded by the Office, Chief of Engineers, U. S. Army (OCE). The objective of the CASE Project is to acquire and/or develop computer-aided design programs for various Corps-type structures. A CASE task group on bridges under the chairmanship of Mr. William E. Galyean, Huntington District, evaluated several bridge programs and recommended seven of these for Corps-wide use. The task group's findings are published in a separate report.

The appendices to this report contain the raw data from the survey. Copies of the appendices are available upon request by contacting Dr. N. Radhakrishnan, Special Technical Assistant, Automatic Data Processing (ADP) Center, WES.

Dr. Som P. Virk, Structural Systems Analyst at Multisystems, was the principal investigator. Other investigators were James J. Kotanchik, Manager, Management and Engineering Systems Division, at Multisystems; Oral Buyukozturk, Associate Professor of Civil Engineering, Massachusetts Institute of Technology; Daniel Roos, Professor of Civil Engineering, MIT; Dr. Schelling, Associate Professor of Civil Engineering, University of Maryland; Kenneth M. Will, Assistant Professor of Civil Engineering, Georgia Tech; and Leroy Z. Emkin, Associate Professor of Civil Engineering, Georgia Tech. Robert D. Logcher, Professor of Civil Engineering, MIT, reviewed the work from time to time.

The entire study was performed under the general supervision of Dr. Virk. Work at Multisystems was done under the direct supervision of Dr. Virk assisted by Mr. Kotanchik and Professors Buyukozturk, Roos, and Logcher. The work at Georgia Tech was performed under the supervision of Professors Will and Emkin assisted by Ms. Catherin Bigelow, Ms. Toni Serena, Mr. Marvin Long, and Mr. Pierre LeBeouf, Research Assistants. The work at the University of Maryland was performed under the supervision of Dr. Schelling assisted by Douglas Neary, Research Assistant.

Dr. Radhakrishnan monitored the work under this contract. OCE point of contact was Mr. Donald R. Dressler, Structures Branch, Civil Works Directorate. Mr. Donald L. Neumann was Chief of the ADP Center during preparation of this report.

COL J. L. Cannon, CE, and COL N. P. Conover, CE, were Directors of WES during the preparation of this report. Mr. F. R. Brown was Technical Director.

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SUMMARY

The objective of this report is to review and recommend bridge oriented application software which can be used in a production environment by the U.S. Army Engineer Waterways Experiment Station. Included herein details a comprehensive study of current practice and computer programs relating to the design of bridge and bridge related structures. Also, as a result of the study is a classified inventory of bridge design software was compiled which can be used for general reference. In oraer to accomplish this, two steps were involved. The first step was the collection, through a first mailing, of the application software documentation, its evaluation, and the utilization of the findings in establishing a fundamental selection criteria. The second step was to construct a questionnaire containing a fundamental selection criteria in the form of a set of design features, and to get the questionnaire evaluated by the user. In addition of the bridge analysis and design features, the questionnaire also included the queries concerning the system software and organizational data.

The areas of interest were broken down into superstructure, geometry, substructures, piles and system.

In the area of superstructure, documentation was received for 109 bridge superstructure programs in response to the initial mailing. The programs were evaluated using 180 feature requirements. The status (mandatory, desired, etc.) of each of the features was determined from the responses to the questionnaire. Five programs were selected for an in-depth reievw in Phase II, using criteria based on overall rating and generality documentation, modularity, and current status. The programs selected for further study are:

1. "The Maryland SHA Bridge Design, Rating and Routing System", Maryland State Highway Administration, Department of Transportation.

2. "Design of Prestressed Concrete Girders", Texas State Department of Highway and Public Transportation.

3. "Analysis of Prestressed Concrete Box Girder Bridges (GIRDER PC)", California Department of Transportation.

4. "Bridge Rating and Analysis of Structural Systems (BRASS)", Wyoming State Highway Department.

5. "Design of Reinforced Concrete Box Girder Bridges", California Department of Transportation.

In the geometry area, documentation was received for twenty-five bridge geometry programs in response to the initial mailing. The programs were evaluated using thirty-six feature requirements. The status of each of the features was determined from the responses to the questionnaire. Two programs were selected for an in-depth review in Phase II, using criteria based on overall rating and generality, documentation, modularity, and current status. The programs selected for further study are:

1. "The Geometry Solution of Highway Bridges", Georgia Department of Transportation.

2. "BELEV", Kentucky Department of Transportation.

In the area of substructures, documentation for forty-five computer programs was received in response to the initial mailing. The programs were evaluated using 146 feature requirements. The status of each of the features was again determined from the questionnaire responses. None of the programs were found to adequately satisfy the criteria based on generality, documentation, modularity, '77' code requirements, and current status. However, three of the programs were selected for review in order to satisfy the less stringent criteria as stated in the original proposal requirements for functional modules. The three programs selected for an in-depth review are:

1. "Pier Design", Michigan Department of Transportation.

2. "The Analysis of Multiple Column Piers for Highway Bridges", Georgia Department of Transportation.

3. "Pier Design for Bridges", Century Engineering, Inc.

In the area of pile group foundations, documentation for only nine computer programs was received as a result of the request made in the initial mailing. The programs were evaluated using 80 feature requirements, and the status of each of the features was again determined from the questionnaire responses. Four out of nine programs rated above average, and two of the four programs were selected for a more detailed review in Phase II. None of these two programs utilize the flexure formula, and both of them employ the very general stiffness matrix analysis technique. The programs selected for further study are:

1. "Analysis of Pile Group Foundations", Maryland State Highway Administration, Department of Transportation.
2. "The Analysis of Pile Group Footings", State of Maine, Department of Transportation.

CHAPTER I

INTRODUCTION

The potential use of digital computers in bridge design is extensive. However, that potential use has not been fully realized to date. The current status of the art can be described as a fragmented effort. Over 700 bridge computer programs have been developed to solve specific problems on specific computers.

The objective of this effort is to provide modular bridge design software encompassing current bridge design specifications and allowing a design engineer a wide range of interaction with the computer in performing his design functions. Such software should be able to perform the design of a variety of typical bridges.

The development of comprehensive computer programs would:

1. Permit alternative approaches and solutions to bridge design problems.
2. Result in cost-effective engineering and optimal use of materials and personnel.
3. Save significant time in the total design process.
4. Permit changes in bridge design specifications to be incorporated with relative ease in strategic points in the design process.
5. Minimize duplication in computer program development.

The purpose of this effort was to perform a comprehensive study of current practices and computer programs relating to bridge design. The study had the following objectives:

- to quantify current bridge design needs.
- to develop detailed specifications for the selection and modification of existing programs.
- to identify a useful set of existing bridge programs which can be implemented directly at reasonable cost and effort.

This report contains the findings of the effort and is divided into the following sections:

1. State of the Art Assessment - Through site visits, mailings and questionnaires, information was obtained on the current state-of-the-art in bridge design. Various state highway and transportation agencies were contacted to determine what procedures they currently follow and to what extent if at all they utilize computers in their design projects. By analyzing these results the study team could determine the range of different design approaches and computer systems currently in use.
2. User Requirements and Component Selection - Those characteristics which the user felt should be included in bridge design software are presented. The areas of interest were broken down into superstructure, geometry, piles and piers. The user requirements were compared with the capabilities of existing software and the top candidate programs were identified in each area based on the user requirements. The top programs were then evaluated against a set of global criteria, and those satisfying the criteria are recommended.

CHAPTER 2

APPLICATION SOFTWARE EXPERIENCE AND SELECTION

2.1 INTRODUCTION

The final test of the success of a computer program is the level of its utilization. The ideal system would be on which would be used by most of the bridge design agencies in the public as well as the private sectors. However, this is an especially difficult task because the design methods employed by these agencies as well as the modes under which they might access the computer are so divergent.

This chapter is devoted to the collection of data and information on practices which are currently being employed by the various state agencies and private consultants involved in the analysis and design of bridge related structures. Such information entails a detailed analysis of many factors including, but not limited to: an assessment of the software that is available and being used; the current level of automation along with the major impediments to an effective utilization of the computer in design; the requirements of the design agencies with respect to application software. However, even considering the great amount of information on current bridge design practices and computer programs, it was necessary to delete much material due to space limitation. Specifically, material pertaining to the programs and practices relating to seismic effects, to special bridge types (such as arches, suspension bridges, etc.) were omitted. Also, the detailed backup data which describes the vists to California, Maryland and Georgia DOT is not included. A detailed description of the procedure used in collecting the information will be presented. The collected information will then be used in defining the current analysis and design practices, and in establishing a selection criteria for existing application software. The components satisfying the selection criteria in each of the four areas of interest: superstructure, geometry, piles, and piers, will then be selected and a brief discussion of the selected components will be presented.

2.2 DATA COLLECTION AND SOFTWARE INVENTORY

In this section, a complete description of the procedures utilized to collect data and information on bridge design oriented computer program and design practices is presented. The procedure involved two steps. The first step was the collection of application software documentation, its evaluation, and utilization of the findings in establishing a fundamental selection criteria. The second step was to construct a questionnaire containing the fundamental selection criteria in the form of a set of design features, and to get the questionnaire evaluated by the user.

2.2.1 Collection of Application Software Documentation (First Mailing)

The procurement of documentation which describes existing software capabilities was carried out through close cooperation with the Highway Engineering Exchange Program (HEEP) and the Society for Computer Applications in Engineering, Planning and Architecture (CEPA). Contact with HEEP allowed full access to all domestic state highway organizations as well as the Canadian provincial highway design agencies. CEPA provided access to 190 private consulting, industrial organizations as well as certain municipal design agencies. Although the CEPA membership represents only a small fraction of the approximately 30,000 consulting organizations, it does contain a high degree of expertise and experience in computer application far out of proportion to its number.

The documentation for the various bridge geometry, superstructure, pier and bent, and pile production programs was requested individually by direct mail from 63 state and Canadian design agencies as well as from each of the CEPA members (see Exhibit A-1 of Appendix A). Each mailing was accomplished by a cover letter from the HEEP organization emphasizing the need for the request (see Exhibit A-2 of Appendix A). The request resulted in a 75 percent response from 47 governmental and provincial design organizations with documentations submitted for 222 programs. The respondees are summarized in Table A-1 of Appendix A - Summary of Government Agency Responses for Software Documentation. Documentation for 11 programs was also received from 30 percent of the CEPA member firms with many also indicating they they were not engaged in bridge design.

2.2.1.1 Compendium of Application Programs: A direct result of Phase I study effort was the collection and evaluation of the documentation for 25, 109, 45 and 9 analysis and design programs in bridge geometry, superstructure, pier and pile group, respectively. The data obtained as a result of this evaluation effort was not only used as a basis for the selection of sub-programs for use in design of bridge structures, but also as information which would be included in a compendium of computer programs for use by bridge design engineer.

The compendium is composed of a series of 36 tables which summarize in detail the features contained in each program (see Table 1, Compendium of Bridge Design Programs). The first tables (e.g., Tables A-2, B-1 and B-2 for superstructures, Table

APPLICATION	LOCATION	TABLE	IDENTIFICATION
BRIDGE SUPER-STRUCTURE	APPENDIX A	A-2	Program Identification - Superstructures
	APPENDIX B	B-1	System Data - Superstructures
		B-2	General Program Data - Superstructures
		B-3	Analysis Capabilities - Superstructures
		B-4	Loading Capabilities - Superstructures
		B-5	General Design Data for Plate Girders and Rolled Section Bridge Programs
		B-6	Design Details for Plate Girder and Rolled Beam Bridges
		B-7	General Design Data Prestressed Concrete Bridge Programs
		B-8	Design Details for Prestressed Concrete Bridge Programs
		B-9	General Design Data for Reinforced Concrete Bridge Programs
		B-10	Design Details for Reinforced Concrete Bridge Programs
BRIDGE GEOMETRY	APPENDIX A	A-3	Program Identification - Geometry
	APPENDIX C	C-1	System Data - Geometry
		C-2	General Program Data - Geometry
		C-3	Analysis Capabilities - Geometry
		C-4	Analysis Capabilities (continued) - Geometry
		C-5	Rating Summary for Geometric Design Programs
		C-6	Summary of Geometry Programs Usage and Rating
BRIDGE SUB-STRUCTURE	APPENDIX A	A-4	Program Identification - Substructures
	APPENDIX D	D-1	System Data - Substructures
		D-2	General Program Data - Substructures
		D-3	Analysis Capabilities - Substructures
		D-4	Loading Capabilities - Substructures
		D-5	Output Options - Substructures
		D-6	Column Design Data
		D-7	Cap Design Data
		D-8	Footing Design Data
		D-9	Design Details - Substructures
		D-10	Rating Summary for Substructure Design Programs
		D-11	Summary of Substructure Program Usage and Rating

Table 1. Compendium of Bridge Design Programs

APPLICATION	LOCATION	TABLE	IDENTIFICATION
BRIDGE PILES AND GROUPS	APPENDIX A	A-5	Program Identification - Piles
	APPENDIX E	E-1	System Data - Pile Group Foundations
		E-2	General Program Data - Pile Group Foundations
		E-3	General Program Limitations - Pile Group Foundations
		E-4	General Program Options and Capabilities - Pile Group Foundations
		E-5	Design/Analysis Data for Pile Group Foundation Programs

Table 1. Compendium of Bridge Design Programs (continued)

A-3, C-1 and C-2 for bridge geometry, etc) have been standardized for all four application areas. The Tables contain information which will allow the user to determine:

1. The origin of the program;
2. The basic methods utilized in the program;
3. The computer hardware the program is now operating on;
4. The basic input/output modes;
5. How the program is constructed (if available);
6. The type of maintenance available;
7. The status of the documentation;
8. Whether the program is available or proprietary;
9. The size limits of the problems the program can handle;
10. The specific analysis capabilities;
11. The design specifications used;
12. A detailed list of specific features applying to the four program application types (e.g. for superstructures the list contains information concerning the LL options, whether the program rates bridges, cover plate options, etc).

Coupled with this, a one page abstract was developed for each program giving even more detailed information (see Exhibit A-3 of Appendix A for a sample). Thus, the compendium allows the user to obtain a level of information which would be required when making a preliminary evaluation of available software. The tables also allow the user to quickly compare the various program features in making an assessment.

2.2.1.2 Software Inventory Procedures - In order to adequately continue inventory the many computer programs over the four application areas (i.e. geometry, superstructure, pier and bent and pile) it was necessary to determine the global requirements of all state, provincial and consulting organizations engaged in bridge design. To accomplish this, a detailed set of program features were obtained as outlined in steps 3 and 4 in Figure 1, and are described in details as follows:

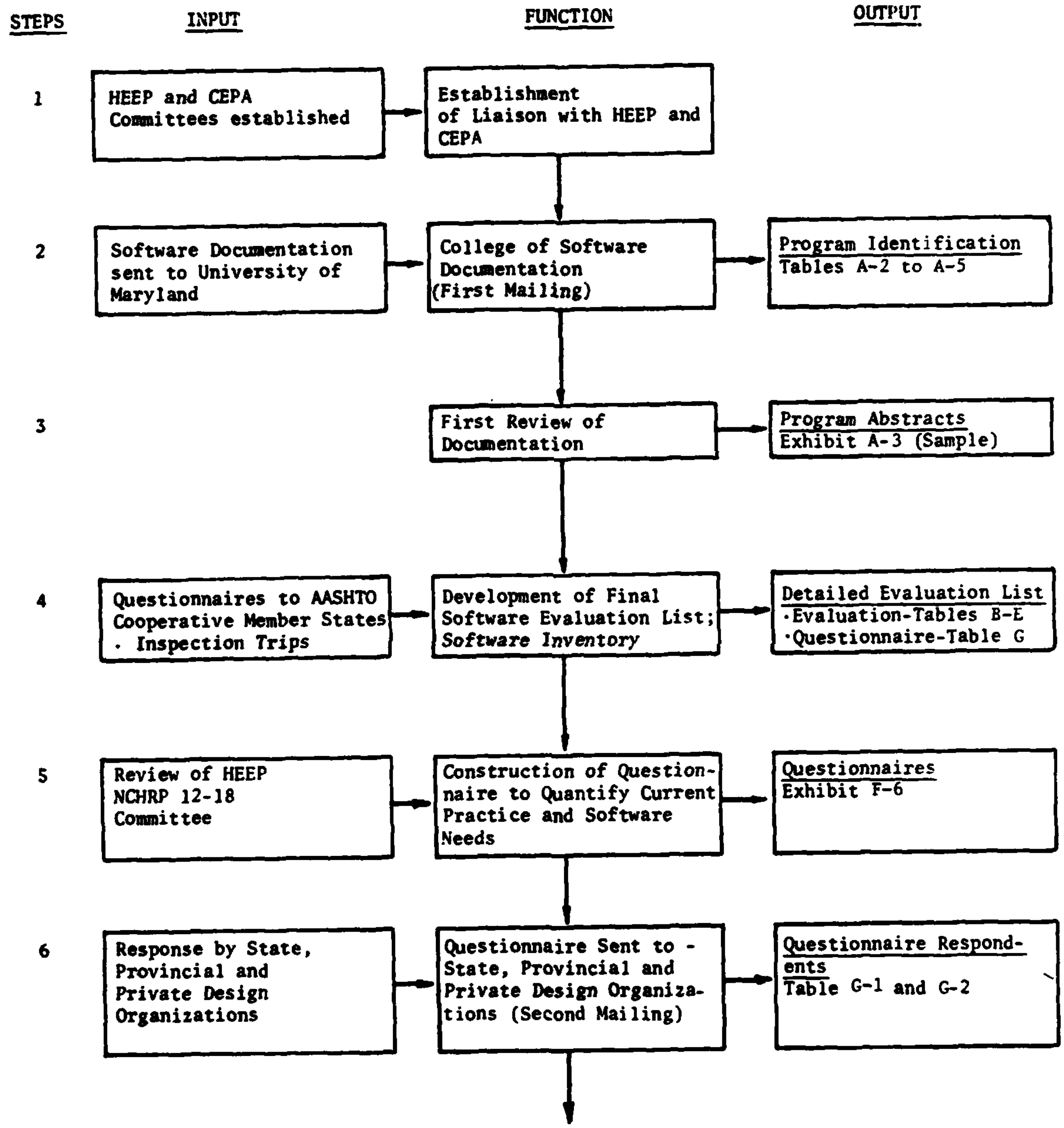

Figure 1. Flowdiagram for Phase I

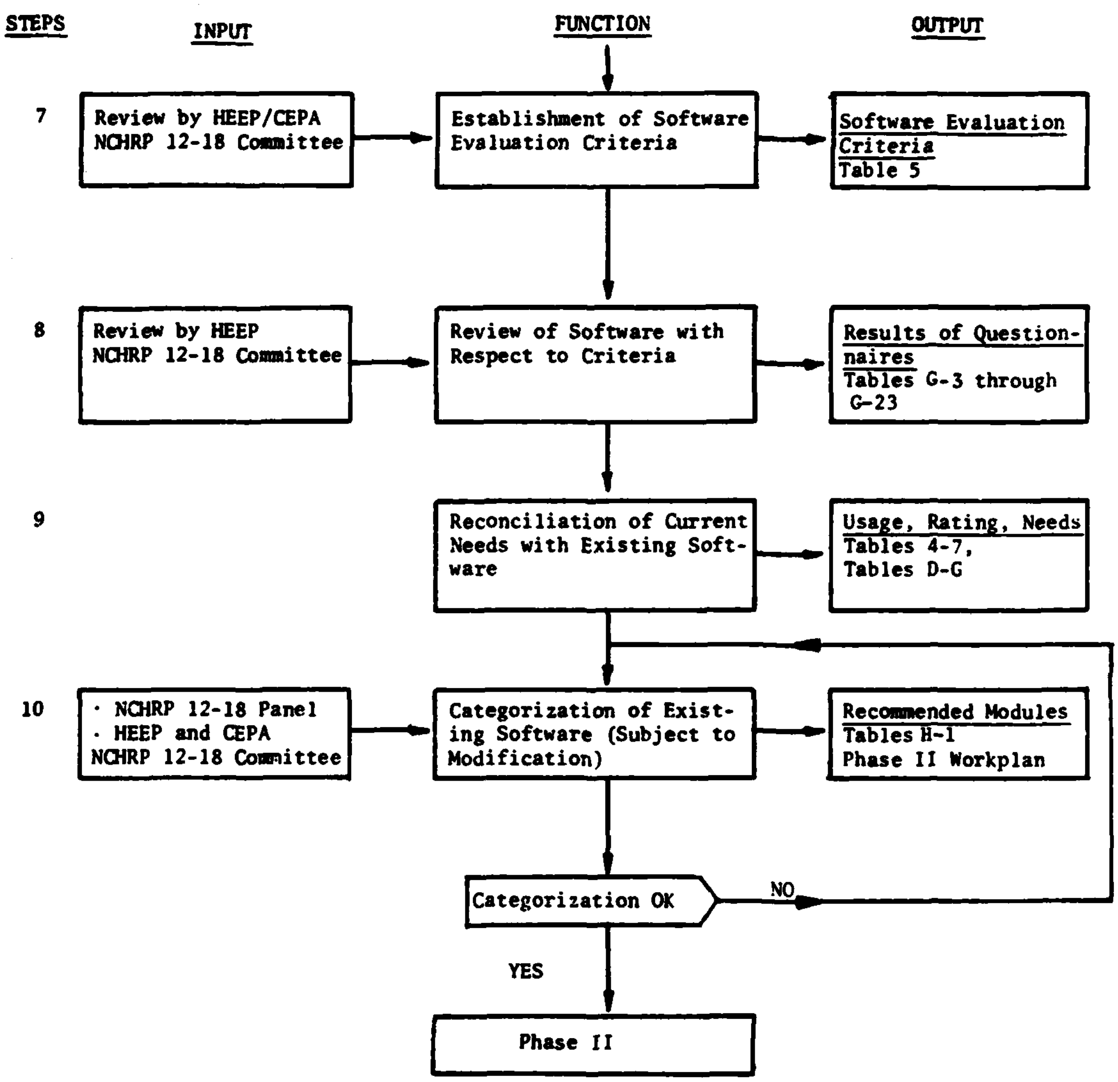

Figure 1. Flowdiagram for Phase I (continued)

1. A preliminary review of all software documentation was made in order to establish a set of global features currently in use (although not all available in one program);
2. A list of the requirements of the Southern Area AASHTO states (which had been obtained prior to the NCHRP 12-18 project by Georgia DOT for use on the development of the Maryland Bridge Design System) were used to supplement the list obtained from the various software packages;
3. A list of additional requirements were obtained through experience and through inquiry of various users;
4. Finally, the list was reviewed by the HEEP NCHRP 12-18 Committee and supplemented with additional user requirements.

The resulting set of 462 program features can be found in Appendices B through E as summarized in the following:

APPLICATION	NO. ITEMS	TABLES
Superstructure	180	B-1 to B-10 (Appendix B)
Geometry	36	C-1 to C-6 (Appendix C)
Piers and Bents	146	D-1 to D-11 (Appendix D)
Piles	100	E-1 to E-5 (Appendix E)
TOTALS	462	

It must be emphasized that the list of items given within the tables represent overall requirements of which existing capabilities compose a subset. These requirements are key within this study, they being used not only in the software compendium as a summarization of capabilities, but also as a means of rating or comparing each program with another and determining the adequacy of existing software. The full nomenclature and definition of tems can be found in Appendix F, Exhibit F-1.

2.2.2 The Questionnaire (Second Mailing)

One of the predominate reasons why many highway departments are not making use of existing design systems is that

insufficient attention was given to the review of design practice when the programs were developed. As determined in the previous section, the level of program utilization (or acceptance) is directly dependent upon the general capability of the program. Thus, one very important step required to insure the success of a system is to first specify in detail what features are required by the users. In order to obtain detailed information necessary to determine both the current computer related bridge design practice and the adequacy of the existing bridge design software and to accomplish the user's requirements, it was necessary to resort to a questionnaire which was targeted primarily to the state design agencies and secondly to the private consulting firms comprising CEPA.

The items within the questionnaire relate to several apsects of current bridge design practices. These can be found in the "Questionnaire on Current Computer Oriented Bridge Design Practice" in Appendix F, Exhibit F-6. Specifically, parts 2.0 through 4.0, the first 5 items of part 6.0 through 9.0 and part 10 refer to topics other than particular program features within each application area. Thus, a significant part of the questionnaire is devoted to such questions as computer utilization, program development, sources and users of programs, etc. The results of these questions are summarized in Appendix G, Tables G-3 through G-5.

The process of constructing, mailing and evaluating this questionnaire is outlined in steps 4 through 8 of Figure 1, and a detailed description of these steps is presented in the following sections.

2.2.2.1 Construction of the Questionnaire - The questionnaire was developed in order to obtain information in eight basic areas as follows:

1. The current system software requirements and the application software requirements for bridge geometry, superstructure, piers and bents and pile groups;

2. The application software that is currently being used (obtained from a list of known programs given in Section 2.2.1 of this report);

3. The requirement level of experience and familiarity of the state organization with respect to features of an integrated bridge design system;

4. The level of software development activity in the bridge design area as well as the numerous other factors affecting the dissemination, coordination, economics, education, etc. pertaining to engineering program and program development;

5. The identification of the current impediments to the effective use of the computer by state and consulting organizations;

6. A determination of the hardware, perpetual equipment, modes of operation and languages currently in use by the state and private consulting organizations;

7. The amount of in-house design currently being done by state agencies indicating level to which the various functions are automated.

8. The verification of the program evaluation accomplished in Section 2.2.1 of this report (steps 2 and 3 shown in Figure 1)

In order to obtain the information in sufficient detail so as to be useful for the bridge geometry, superstructure, pier, pile group and system levels, it was necessary to construct an extensive 32 page questionnaire. This questionnaire contained 565 individual queries segmented into ten parts (see Appendix F, Exhibit F-6).

The questionnaire itself was constructed from information obtained from the following six basic sources:

1. Information gained from a review of superstructure design requirements on the Southern Area AASHTO States conducted by Glen Sykes of Georgia DOT;

2. A review of the features contained within the existing application programs (first mailing);

3. Experience gained by the Multisystems research team in the development of system software and by the University of Maryland and Georgia Institute of Technology research teams in the development of bridge design oriented software;

4. Suggestions made by the HEEP NCHRP 12-18 Committee assigned to provide input to the project from the state agencies (with Alen Cole from New York, DOT as Chairman);

5. Suggestion made by the CEPA NCHRP 12-18 Committee assigned to provide input to the project from the private consultants (with Robert Scibelli from Civil Systems as Chairman);

6. Information obtained from a direct inspection trip to California DOT in Sacramento and through a sustained working relationship the University of Maryland research team has with the Maryland State Highway Administration, Bureau of Bridge Design.

It must be pointed out that this current experience level in computerized bridge analysis and design demands a detailed level evaluation of current capabilities and needs. No superficial evaluation would be adequate. Further, it is felt that the information obtained from the questionnaire is unique and will serve to aid in determining bridge design software requirement for some time to come.

2.2.2.2 Response to Questionnaire - The questionnaire was directed mainly to 51 domestic states, territories, and 12 Canadian provincial bridge design agencies. A secondary mailing was also sent to 190 private consulting firms (with a few University and municipal design bureaus) represented by CEPA.

The questionnaire mailing to the various state agencies was coordinated through the HEEP organization by a cover letter soliciting support for the survey (see Exhibit F-2, Appendix F). The mailing itself consisted of the following:

1. A cover letter from HEEP (see Exhibit F-2, Appendix F);
2. A letter from the University of Maryland (see Exhibit F-3, Appendix F);
3. The questionnaire (see Appendix F, Exhibit F-6);
4. An explanation of the nomenclature utilized in the questionnaire (see Exhibit F-1, Appendix F);
5. A copy of the preliminary evaluation of the application program for each respective state with a request that correction be made;
6. A list of all application program with a request that each state identify what programs they were using.

Thus, the states were requested to supply a substantial amount of information involving not only the questionnaire, but a verification of the features contained in the various programs evaluated and an assessment of what programs were in use. Despite the amount of effort required to complete the mailing, a 52% rate of return was experienced. Out of a total of 63 questionnaires mailed to the state and provincial agencies, 38 were returned (60%). 33 of the returned questionaires were completed, which is 52% of the total questionnaire mailed. A complete list of these agencies is presented in Table G-1 of Appendix G. The specific contacts for each organization are given in Table G-2 of Appendix G.

The questionnaire which was sent to the private consulting firms was coordinated through the CEPA organization. Again, a cover letter was sent along with the questionnaire (Exhibits F-4 and F-5 of Appendix F) asking for support. No other material was forwarded with this mailing except the definition of nomenclature. Again, the return for this mailing was excellent considering the complexity and extent of the questionnaire. Out of a total of 190 questionnaires mailed, 58 were returned (30%) and 27 were completed (or 50% of those returned). Those firms that did return the questionaaires but did not complete it indicated that no bridge design was done by their organization. A breakdown of the total responses of the

CEPA response can be seen in Appendix G, Table G-1. The specific contacts for each organization are given in Table G-2.

2.2.2.3 <u>Processing of the Returns of the Questionnaire</u> - The information which was obtained from the response to the questionnaires can be grouped into either the application data category (for bridge geometry, superstructure, pier and pile group and seismic information) and the systems data category. Discussed in this chapter are the results and the procedures used for the reduction of the data in the applications category only. The results and procedures used for the reduction of the data in the systems category will be discussed in the next chapter.

The part of the questionnaire which pertains to the applications category is given under Sections 6.0 through 10.0 of the "Questionnaire on Current Computer-Oriented Bridge Design Practice" (See Appendix F, Exhibit F-6). Within these sections are contained the bulk of questions (<u>87</u>%). Specifically, Sections 6.0, 7.0, 8.0, 9.0, all begin with a series of five common questions relating to general informaton for the bridge geometry, superstructures, pier and piles group application areas, respectively. A sixth question, which is also specified for each application area, required that the respondent complete a lengthy set of questions in tabular format (see Exhibit F-6, Tables 6.6, 7.6.1 through 7.6.8, 8.6.1 through 8.6.5, and 9.7.1 through 9.7.3), which represents the overall global requirements for the application software categories investigated. Specifically, the respondent was asked to make an assessment as to whether the feature listed is either a mandatory, desired or required. <u>In this way the design engineer as a user specified the features that are needed in practice</u>.

It is worthwhile to note that approximately 75% of the items given for all application areas were rated as mandatory by over 67% of the respondees. This agreement indicates that the features being considered are required by the practicing profession and that the users are technologically knowledgeable with rather high expectations. This was also borne out both by

the visitations to the California DOT and via contact with the HEEP NCHRP 12-18 Committee.

After the application portion of the questionnaires was tabulated (see Tables G-6 through G-23) a method of comparing the individual program with the features was then developed. The specific procedures used in this process are shown in Figure 2; Program Rating and Ranking Procedure. Here a series of seven steps are outlined which are described as follows:

Step 1: The questionnaires are received from the state design agencies and are tabulated in Tables G-6 through G-23 of Appendix G.

Step 2: The criteria is established to rate the 463 features as Major Mandatory (M+), Mandatory (M), Desired (D), or Not Required (NR). These are described in Table 2 - Feature Rating Criteria, (where for example, if 66.7% of the states specify a feature as mandatory, then it receives M+).

Steps 3, 4: The features are then rated *for the first time which* is shown in Tables G-6 through G-23 as well as throughout the compendium in Appendices B, C, D and E.

Step 5: A ranking procedure is then developed where by each program can be evaluated with respect to the global application requirements. This ranking procedure is shown graphically in Table 3 - Numerical Ranking, and is intended to provide all allowable acceptable combinations of item ratings (M+, M and D). For example, a program in a specific category, (say DL in bridge superstructure) may have satisfied all the M+, less than 50% of the M and none of the D categories. It then would receive a subrating of 7. for DL. A program which has not met any of the M+ or M ranking would not be acceptable. This method does provide a differing scale for each application area evaluated (i.e. the bridge superstructure category has a total of 140 possible points, and the pile group application

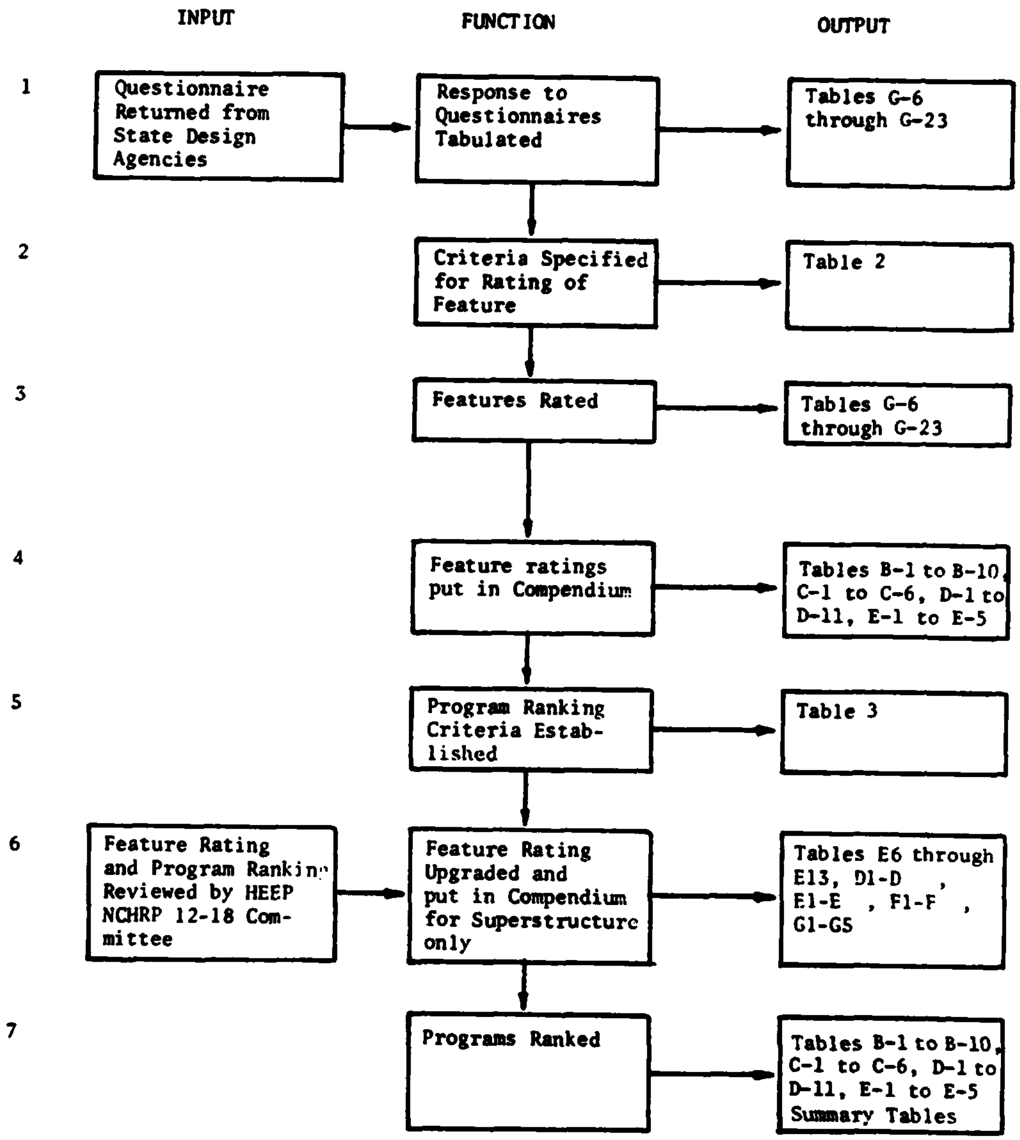

FIGURE 2 Program Rating and Ranking Procedures

Rating		Description
Major Mandatory Feature	M+	66.7% or greater of the states specifying as mandatory
Mandatory Feature	M	33.3% or greater but less than 66.7% of the states specifying as mandatory
Desired Feature	D	33.3% or greater of the states specifying as desired
Not Required	NR	Less than 33.3% of the states specifying as desired

Table 2: <u>Feature Rating Criteria</u>

Numerical Rank	Feature Status			Contents
	Major Mandatory (M+)	Mandatory (M)	Desired (D)	
12	●	●	●	Acceptable
11	●	●	◒	
10	●	●	○	
9	●	◒	●	
8	●	◒	◒	
7	●	◒	○	
0	●	○	●	Unacceptable
0	●	○	◒	
0	●	○	○	
6	◒	●	●	Acceptable
5	◒	●	◒	
4	◒	●	○	
3	◒	◒	●	
2	◒	◒	◒	
1	◒	◒	○	
0	◒	○	●	Unacceptable (through all remaining combinations)
0	◒	○	◒	
0	◒	○	○	
↓	↓	↓	↓	

● = 100%   ◒ ≥ 50%   ○ < 50%

Table 3: <u>Numerical Ranking</u>

only 108. It is felt that the method does give an adequate spread in points needed for a proper evaluation. However, an exception to this ranking scheme is made when a category has several features but only one is rated as M or M+. Programs that meet at least 50% of the other features in that category are given credit for filling half of the M or M+ features, and are scored accordingly.

Step 6: The feature rating and program ranking procedures are reviewed and approved by the HEEP NCHRP 12-18 Committee. The feature rating for the superstructure application is upgraded.

Step 7: The programs are ranked numerically, the results of which are shown in Tables B-1 through B-10, C-1 through C-6, D-1 through D-10 and E-1 through E-5.

The processing of the first five questions of Sections 6.0 through 9.0 and all questions in Section 10.0 are summarized in Tables G-3, G-4 and G-5 of Appendix G. The results from these tabulations are used in the following sections.

2.3 DEFINITION OF CURRENT PRACTICE

One of the important tasks of Phase I was to perform a detailed investigation of current design practices which are prevalent within the various state agencies engaged in bridge design. This was done in order to form a feasibility criteria to form and evaluate the specifications of an integrated system. Such a criteria, being based upon current practice, would be used throughout Phase I as a benchmark upon which to judge whether the system would be successful is practice.

The components required to define current practice and to form the basis of the criteria fall into four categories: current design activities, existing software capabilities, programming activities and overall computer and program utilization. These are discussed in detail in what follows.

2.3.1 Design Activities

All domestic state and Canadian Provincial highway agencies that participated in the survey engage in the design of bridge and bridge related structures. Most agencies have a heavy committment to the design of highway structure as Table G-3 of Appendix G will attest. Here, a total of 1141, 883, 1033 and 854 state employed engineers and technicians have been identified who perform analysis and design in the bridge geometry, superstructure, pier/bent, and pile application areas, respectively. If these values where extrapolated to include those domestic state design agencies which did not respond to the survey (48%), a total of 2,377, 1,840, 2,152, and 1,779 engineers and technicians could result respectively. This total would require an approximate annual expenditure of from $94,041,603 to $197,181,600 for salaries and salary costs for the state and provincial agencies alone.

Table G-3 also shows corresponding information for the predominantly private consulting-oriented CEPA membership. Such organizations perform about 23 percent of the bridge design for the state organizations (see Table G-4 of Appendix G). It is estimated that there are approximately 30,000 private civil engineering consulting firms in the United States, most of which have fewer than ten employees. No attempts were made to obtain information of these organizations other than through CEPA. However, it is generally agreed that the non-state highway design force within the private, county, and municipal sector is extremely large, with about one-third of them utilizing the computer.

The total annual salary costs for engineers and technicians engaged in the bridge goemetry, superstructure, piers/bent, and pile design function for all state-related projects could be estimated by utilizing the information in Tables G-3 and G-4 as follows:

$$C_{SD} = (N_S + N_{A1} M_{NR}) W_A \left(1 + \frac{P_C}{100}\right) \quad . . . (Eq.\ 1)$$

Where C_{SD} = Total estimated annual salary costs for engineers and technicians engaged in bridge geometry, superstructure pier, and pile design function

N_S = Average number of staff identified (Table G-3, Column (1))

N_{A1} = Average number of staff per agency (Table G-3, Column (2))

M_{NR} = Number of government agencies which did not respond

W_A = Average annual salary + salary costs for engineers and technicians

P_C = Average percentile performed by outside consultants (Table G-4, Column (2))

It is also possible to obtain an approximate saving potential for the total automation of the bridge design process as follows:

$$S_P = C_{SD} \left(1 - \frac{P_A}{100}\right) (1 - 1/R) \quad . \; . \; . \; \text{(Eq. 2)}$$

Where S_P = Potential annual cost savings for full automation of the design process

P_A = Average percent automated (Table G-4, Column (3))

$$R = \frac{\text{Time required for design using manual methods}}{\text{Time required for design using the computer}}$$

Using these relationships and the data obtained from the study, the following estimates are obtained:

N_S = (1141 + 883 + 1033 + 854)/4 = 978

N_A = (35.66 + 27.60 + 34.43 + 26.70)/4. = 31.09

M_{NR} = (63 states) x (48% response) = 30 governmental agencies

W_A = \$24,200

P_C = (19.8 + 23.0 + 25.7 + 26.70)/4. = 23.1

$$C_{SD} = (978 + 31.09 * 30) * 24,200 * \left(1 + \frac{23.1}{100}\right)$$

= \$56,920,135 per year

which represents the total annual salary cost for engineers and technicians engaged in the design of bridge structures.

By using Equation 2, the total potential annual savings which could be realized if the bridge design function were completely automated can also be estimated. The potential savings computed for bridge geometry, superstructures, substructures and pile application areas are $18,637,580, $23,154,560, $27,548,500, and $24,700,970, respectively, with a total potential savings amounting to $94,041,603. This value is 47% of the total estimated annual expenditure of $197,181,600 for salary costs incurred by government agencies.

Coupled with the quantitative data collected during Phase I is the qualitative information gathered both from the study as well as other sources. This includes information obtained from the various state agencies through visitation, liaison with the HEEP NCHRP 12-18 Committee and other members of the HEEP organization at area and national meetings, through a working relationship with the Maryland, Georgia, Alabama Departments of Transportation, and through various contacts with other state organizations this year (e.g., FHWA short courses, user group meetings, etc.). This information, although "soft," is considered by the research team to be of considerable importance and is given in summary as follows:

1. There exists a high level of interest by the states in generalized production-oriented application software which is current with respect to the AASHTO design specification requirements. This conclusion is substantiated by numberous factors including the high rate of return (52%) of the lengthy 32-page questionnaires, by the support shown by HEEP in forming the special NCHRP 12-18 Committee, and by the general enthusiasm shown by included HEEP members representing various states throughout the Phase I period.

2. The expectation level of the various state design agencies is high in all application areas investigated. Over the years, the state agencies have acquired a high proficiency in the use of computers in the design of bridge structures. Their response to the questionnaires was, therefore, definite and detailed for most application areas queried. A detailed review of the results of the questionnaires pertaining to the categorization of the various superstructure features (see Tables G-6 through G-23) required by the state agencies was made by the HEEP NCHRP 12-18 Committee. The results of this review were that the committee upgraded 95 features from mandatory to major mandatory, and one feature from desired to mandatory.

3. Many of the programs which utilize the newer more advanced techniques are not being widely used by bridge engineers. The general structural analysis system STRUDL, for example, is being used by only 47 percent of the states. Numerous other state-of-the-art programs which have been identified fall far below this usage. The pile group area is an example of how some excellent methods are being overlooked in favor of very approximate analysis techniques. Many reasons have been cited for this reluctance on the part of designers to avoid certain programs, including:

   a. Inertia from the continued use of the same programs over a prolonged period of time.

   b. The disruptive and often expensive process of implementing new programs necessitate the retraining of engineers and the validation of software, and often requires customizing in order to accommodate traditional procedures.

   c. Non-applicability of certain state-of-the-art programs to practical design situation. Specific barriers to utilization of programs of this type

could include: high processing costs or running times; excessive or difficult input; the lack of knowledge (and confidence) on the part of the engineer in the methodology used within the program.

Thus, many impediments exist within the field to the acceptance of new methodology or software. This is understandable, considering that the primary mission and responsibility of the engineer/user is to design.

2.3.2 Existing Software Capabilities

In order to assess the overall capabilities of bridge design software which currently exist within the state and private design organizations, it was necessary to perform an extensive and detailed comparison of the features available within the 222 programs examined with a set of global requirements. These requirements, given in the tables within Appendix B through E, are composed of a set of 462 items which represent a composite of the features both required by the various state agencies and those which currently exist within the programs examined. (The specific procedure utilized to obtain the items is explained in Section 2.2.1.2 - Software Inventory Procedures. A description of each item is given in Exhibit F-1 of Appendix F.)

The global requirements were used throughout the Phase I period for the following:

1. As a means whereby the capabilities of each program could be inventoried and readily compared with a set of standard items by potential users (see the tables within Appendices B through E).
2. As a set of features which could be reviewed by the various state agencies in order to determine what would be required of current state-of-the-art programs. (The specific categories in which the items were indexed were: Major Mandatory (M+); Mandatory (M),

Desired (D), and Not Required (NR). A description of the procedures used to rate the various items is given in Section 2.2.2.3; the rated items are given in Appendix G in tables G-6 through G-23 and appear at the top of the tables in Appendices B through E.

3. As a method whereby the programs reviwed could be rated with respect to a common norm or set of capabilities. This procedure is described in Section 2.2.2.3 and is shown graphically in Tables 2 and 3.

In order to assess the overall capabilities of current bridge oriented application software, it is instructive to review Figure 3 - Program Rating Distribution for Existing Bridge Superstructure Programs. Here, the mean and average program rating for all 109 programs reviewed is 19% and 20%, respectively. Further, about 80% of all programs reviewed fall below a rating of 30%. This means that a great bulk of the bridge application software lacks the sufficient generality to measure up to current requirements.

In practical terms, the lack of a respectable rating means that certain specific and serious deficiencies exist within any program which exhibits a low rating value. The reader should verify this by perhaps selecting a program and trace it through the various items to ascertain its capabilities and limitations.

Of course, the results of the rating given above indicate the level of application capabilities which can be used to solve bridge geometry, superstructure, pier, and pile group problems. Another factor which must be considered when evaluating any program is the structure of the program itself. The program structure is important when considering the requireed portability or the ease with which any program can be transferred from one machine to another. The older programs generally do not exhibit a high degree of portability, in that they are not constructed in a modular manner and therefore are extremely difficult to convert and to upgrade or alter. Most

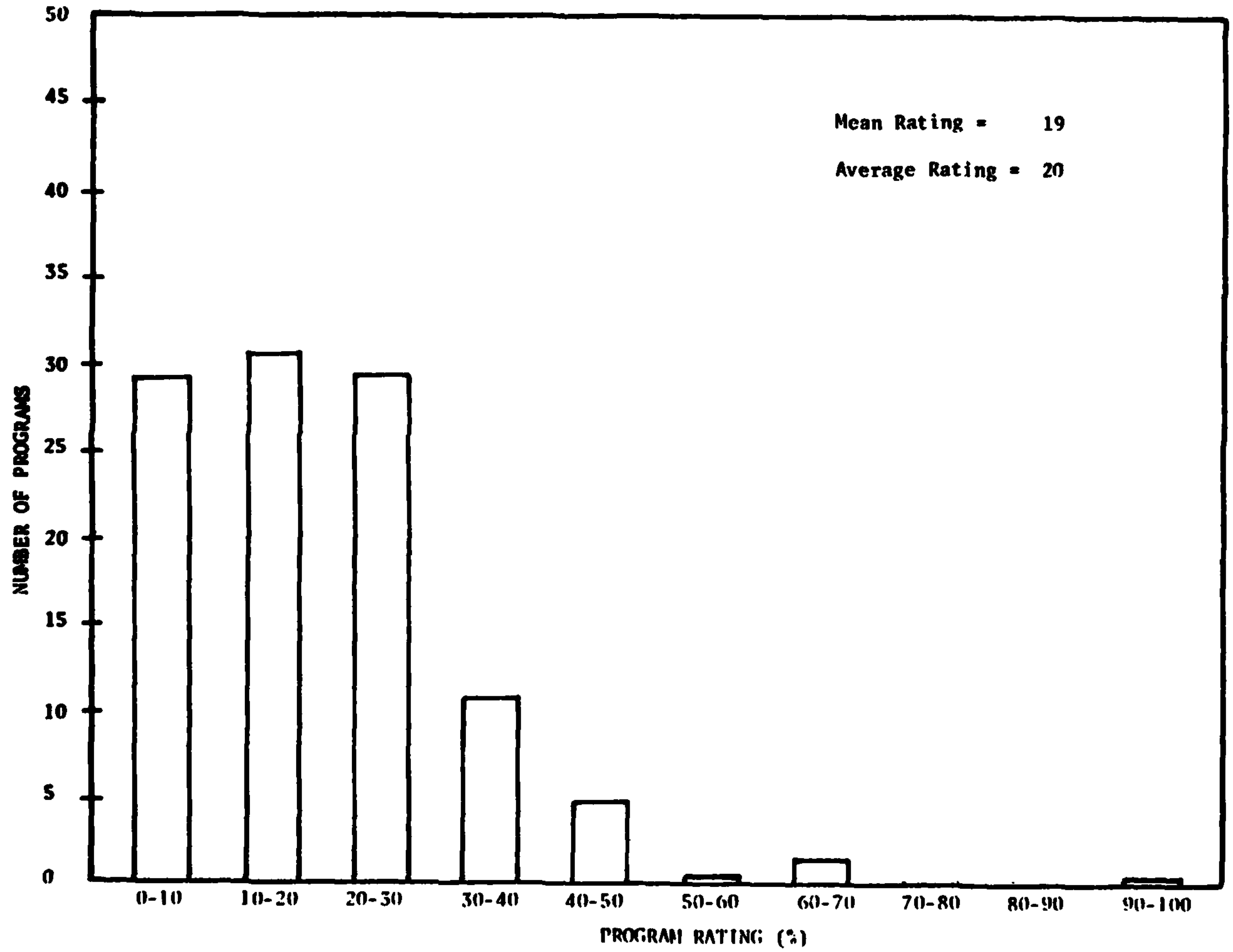

Figure 3 - Program Rating Distribution for Existing Bridge Superstructure Programs

of the programs reviewed in Phase I fall into this category. Unfortunately, there is no way of determining the degree to which this is true, other than obtaining and reviewing the actual programs. However, the experience the authors have had with numerous programs identified herein indicates that the great bulk of programs reviewed, even those with rather high ratings, could be extremely difficult to upgrade or implement.

2.3.3 Programming Activities

All domestic state and provincial highway design agencies and many private consulting organizations contacted engage in the development and maintenance of application software for use in the design of bridge structures. Table G-5 summarizes the current level of engineering and computer staff engaged in these activities for the bridge geometry, superstructure, substructure, and pile foundation applications. From this data, the annual salary costs can be estimated as follows:

$$C_{SP} = (N_P + N_{A2}\, M_{NR})W_A$$

where C_{SP} = Total estimated annual salary costs for engineering and compter staff engaged in program development and support

N_P = Average number of staff identified (Table G-5 of Appendix G)

N_{A2} = Average number of state staff per agency

M_{NR} = Number of state agencies which did not respond

W_A = Average annual salary and salary cost for engineering and computer staff

Summarized in Table 4 are the estimated annual total costs for salaries and hardware support within state and private organization by application area. The projected hardware costs were assumed to be equal to the salary expenditures. Although this assumption may be thought to be high, in light of current tendencies toward radically decreased hardware costs, it remains approximately accurate for hardware support for engineering

TABLE 4 TOTAL ANNUAL COSTS FOR PROGRAM DEVELOPMENT AND SUPPORT

APPLICATION AREA	STATE AGENCIES				PRIVATE FIRMS			TOTAL COSTS = STATE + PRIVATE ($/yr) (8) = (4)+(7)
	IDENTIFIED SALARY ($/yr) (1)	PROJECTED SALARY ($/yr) (2)	PROJECTED HARDWARE ($/yr) (3)	TOTAL COSTS ($/yr) (4) = (1)+(2)+(3)	IDENTIFIED SALARY ($/yr) (5)	PROJECTED HARDWARE ($/yr) (6)	TOTAL COSTS ($/yr) (7) = (5)+(6)	
BRIDGE GEOMETRY	3,847,800	9,826,280	7,826,280	19,500,360	3,121,800	3,121,800	6,243,600	25,743,960
BRIDGE SUPERSTRUCTURE	1,403,600	2,405,480	2,405,480	6,214,560	3,242,800	3,242,800	6,485,600	12,700,160
BRIDGE SUBSTRUCTURE	3,654,200	14,827,340	14,827,340	33,308,880	2,710,400	2,710,400	5,420,800	38,729,680
PILE FOUNDATIONS	968,000	1,846,460	1,846,460	4,660,920	2.081,200	2,081,200	4,162,400	8,823,320
TOTAL	9,873,600	26,905,560	26,905,560	63,684,720	11,156,200	11,156,200	22,312,400	85,997,120

organizations. It should also be pointed out that the data within the table reflect an attempt to estimate complete information for costs for all state organizations via extrapolation and that no such attempt was made for the private consulting organizations.

The results given in Table 4 show an extraordinary level of support for program development and maintenance. Specifically, the total annual salary plus hardware support costs for state organizations alone ranges from an identified cost of $19,747.200* to a projected cost of $63,684,720. When the private organizations are considered, this increases to a range from $42,059,600 per year to $85,997,120 per year.

This data may also be examined in light of the 109 superstraucture design programs that were identified in Phase I and the lack of commonality in the use of these programs by the various state design agencies. Summarized in Figure 4 are the number of states that utilize these programs:

1. 83 or 76% of the programs used by one state and

2. 101 or 93% of the programs are used by two states or less.

Thus, a great amount of programming effort has been expended in creating specialized software tailored to each state design agency. Indeed, the predominant reasons that the various state design agencies engage in program development is that the "capabilities (are) not available elsewhere".

2.3.4 Overall Computer Program Utilization

One of the important but difficult missions of the Phase I study effort was to ascertain the current level of computer utilization and to identify those factors which inhibit the use of the computer within design organizations. Certainly, one obvious criterion which can be used to measure the level of computer utilization is to determine the degree of automation

*Identified total costs (not shown in table), are taken as twice the identified annual salary expenditures.

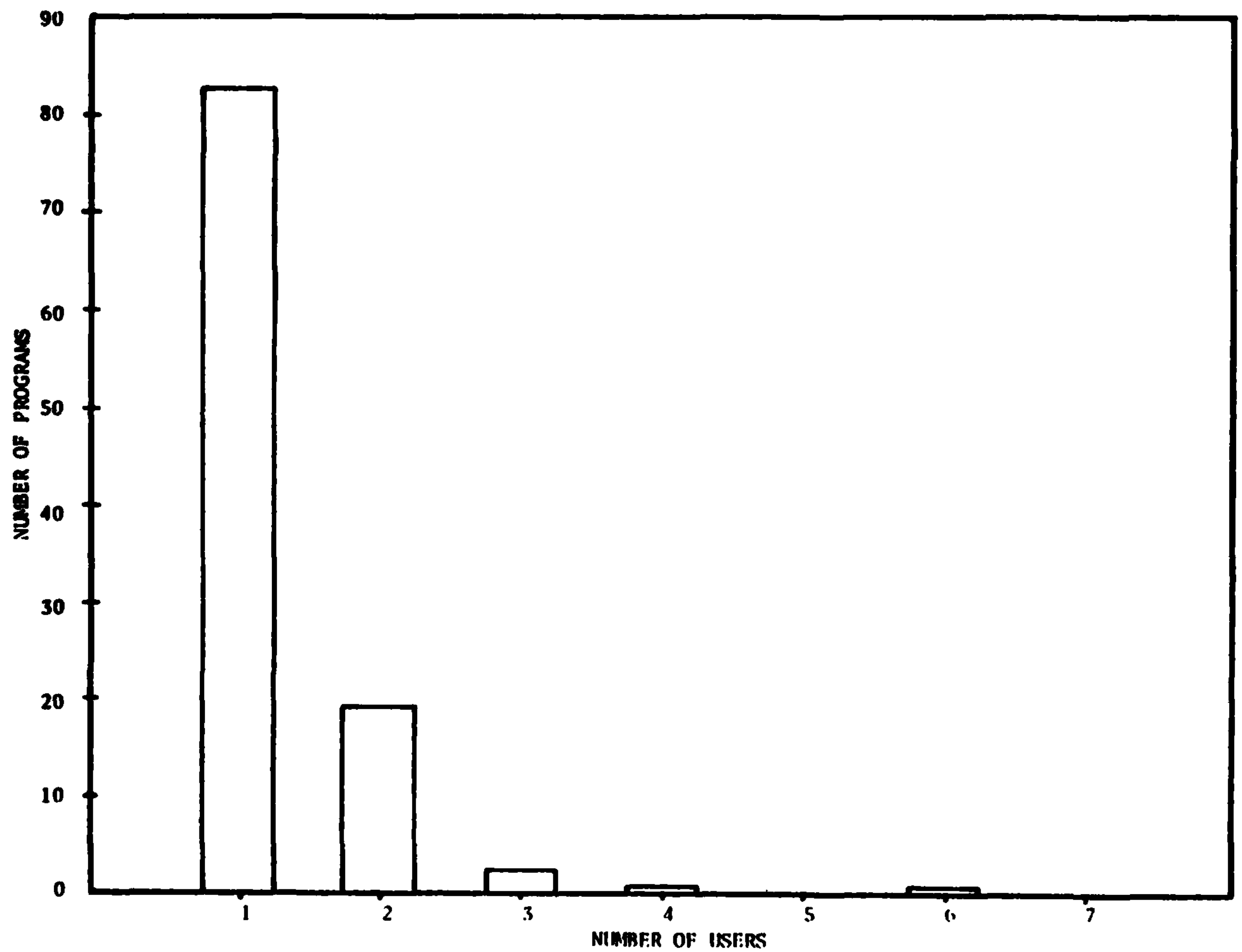

Figure 4. General Utilization of Existing Bridge Superstructure Design Programs

attained for any set of design functions (in this case, bridge geometry, superstructure, substructure, and pile groups). Table G-4 in Appendix G shows the level of automation for each function for both the state and provincial organizations. An estimate for the overall degree of automation can be made by using the following relationship:

$$U = \sum_{i=1}^{4} \frac{N_{si}}{N_T} * P_{Ai}$$

where U = Overall average degree of automation attained by the state agencies and consultants

$N_{S1,2,3,4}$ = The average number of employees engaged in the bridge geometry, superstructure design, substructure design, and pile group design function, respectively. (See Appendix G, Table G-3, Column (1))

$$N_T = \sum_{i=1}^{4} N_{Si}$$

$P_{A1,2,3,4}$ = The percentage of automation attained for the bridge geometry, superstructure design, substructure design, and pile group design function, respectively. (See Appendix G, Table G-4, Columns (1) and (4))

Using the values indicated, the overall average degree of automation attained is 47% for the state agencies, 57% for the private consultants, and an overall average of 48% for all organizations reviewed.

Thus, less than 50% of the bridge design function is automated. This is especially surprising, in light of the fact that the design of bridge structures was one of the first engineering computer applications. However, a lot has occurred in eighteen years; the most significant is perhaps the extreme growth of computer capabilities and the drastic reduction of hardware costs.

In spite of the advantages of advanced hardware capabilities, the general acceptance of the computer in design (which was not always the case) and the acknowledged economic benefits of automated design, there exists a steady state lag in the utilization of the computer in bridge design due principally to the lack of satisfactory programs. Cited in the questionnaire* as first, second, and third most severe impediments to effective utilization are:

1. "Lack of programs incorporating current design codes" (48%)

2. "Lack of useful bridge design-oriented programs" (48%)

3. "Lack of easily usable programs, i.e., cumbersome input and unsatisfactory output" (44%)

Coupled with this, the most cited reason why users do their own development* is: "Capabilities not available elsewhere" (50%). Thus, the degree of utilization of the computer in bridge design is directly dependent upon the available software.

In order to adequately investigate the degree of utilization of existing application programs, it must be realized that bridge designers use software that can be segmented into two distinct groups: the first group consists of general purpose programs which are applicable to a wide variety of applications and, generally, perform little or no design. Examples of these include: STRUDL (47%), STRESS (19%), BRASS (25%), RDS (16%), BARS (13%), SAP (3%) and CUGAR (3%). Thus, these programs enjoy some general acceptance by bridge designers (an overall average of 18% for state agencies) and, because of their design code independence, require little or no alterations but for "bug" fixes or upgrades in analysis capabilities.

The second group of programs consists of those programs which have been developed for specific design applications (such as the design of composite/noncomposite steel "I" beam

*These percentage results have been extracted from the System Portion of the Questionnaire evaluated in the next chapter.

bridges). These programs are generally extremely code dependent and require constant maintenance depending upon the severity of the changes in the specifications. Such programs proliferate the various state software libraries and, indeed, provide the major source of computer capabilities which exists today for bridge design. Specifically, some 180 programs have been identified which fit this category (see Tables A-1 through A-5 in Appendix A).

The utilization of this bulk of software is nearly uniform in that over 80% of the programs are being used by onely one state agency (see Figure 4). Thus, states tend to write their own programs and tailor them to their specific needs. This is done for a variety of reasons including:

1. The lack of generality inherent within the great majority of programs;

2. The lack of knowledge by the users concerning the availability of programs;

3. The great difficulty in converting the various programs from one computer to another;

4. The lack of adequate program documentation (cited by 38% of the users as being a serious impediment to computer utilization);

5. The lack of proper and continuing education related to the computer and the various programs (cited by 44% of the users as being a serious impediment to computer utilization).

Current and past trends indicate that bridge design programs will be continued to be developed (see Table 4 - Total Annual Costs for Program Development and Support). Further, users reason that they will continue to develop software because*: (1) capabilities do not exist elsewhere (50%); (2) it is easier and less expensive than obtaining programs from other sources (31%); and (3) software obtained from outside sources is not adequately documented (31%). As a result of

*These percentages have been extracted from the Systems Portion of the Questionnaire evaluated in the next chapter.

this condition, current software will be underutilized. Also, programming resources will continue to be expended in creating new programs rather than on creating general purpose design software and improving it.

A notable exception to this is the attempt by the Southern Area AASHTO states to enhance various existing computer programs. The consequences of effective cooperation between users can be seen in Figure 4 where the Georgia bridge design program (1202) is used by 6 states. Distribution and knowledge concerning this, and other bridge design programs have been greatly increased by the HEEP and CEPA user groups. What is needed is greater cooperation between the state agencies (such as within the Southern Area AASHTO states) so that high quality general purpose software can be made available and improved, rather than effort expended in creating new software.

2.4 SUMMARY OF THE SELECTION CRITERIA

The selection criteria defined as a basis for the development of an integrated bridge design and analysis system is based on the current practice. The criteria is composed of five general requirements or items each of which carry equal weight within the criteria. This is because it is felt that each item is essential and must be met by all programs which are recommended for inclusion into the integrated bridge design system. A general statement of this criteria along with a summary of the supporting aspects of current design practice (extracted from the previous section and questionnaire responses) is as follows:

Requirement 1.0 - ANY PROGRAM SELECTED MUST BE AS GENERAL AS POSSIBLE WITH RESPECT TO OVERALL APPLICATION CAPABILITY.

Supporting Aspects 1.1 - The diversity of design practice between the state design agencies require the greatest degree of generality;

1.2 - The requirements specified by the various state agencies in the questionnaire and by the HEEP, NCHRP 12-18 Committee were extremely general and are represented by the 147, 33, and 21 Major Mandatory, Mandatory and Desired features, respectively.

1.3 - Those programs which contained the greatest generality are used by the largest percentage (18%) of the states. Those programs which were the most limited in capabilities are used the least (89 or 77% of the programs, are used by only one state).

1.4 - The degree of automation of the bridge design function is low (48%) due primarily to the lack of applicable general software which can be modified with a minimum of effort.

Requirement 2.0 - ANY APPLICATION PROGRAM SELECTED MUST BE ADEQUATELY DOCUMENTED AND CONTAIN USER INSTRUCTIONS, METHODOLOGY, A DESCRIPTION OF THE SYSTEM, AND EXAMPLE PROBLEMS.

Supporting Aspects

2.1 - The lack of adequate documentation was cited in the questionnaire by 38% of the state agencies as being a major impediment to computer utilization.

2.2 - Adequate (external) user documentation was cited by 94% of the state agencies as being the most important feature of a new integrated system.

2.3 - Adequate (internal) documentation was cited by 74% of the state agencies as being the third most important feature of a new integrated system.

2.4 - Of the programs reviewed in Phase I, a high percentage of the programs had inadequate user or internal documentation. Of those programs which had inadequate documentation, almost all of them were in use by only one design agency.

2.5 - Of the 39 software catalogs reviewed in the CEPA/NSF study (Reference 1), no documentation was implemented for 5161 (or 99%) of the program reviewed. It was concluded that: "Documentation forms the only link between the programmer and the user ...absolutely essential for program portability." (Reference 1).

Requirement 3.0 - ANY APPLICATION PROGRAM SELECTED MUST BE CONSTRUCTED SUCH AS TO MEET THE FOLLOWING REQUIREMENTS:

- The programs should be written totally in FORTRAN.
- The effort necessary to convert the program to various computer systems should be minimal;
- The effort necessary to upgrade the program to current specifications should be minimal;
- The effort required to implement various enhancements (such as hanger, support deformation, etc.) should be minimal;
- The effort required to implement various input modes, (such as a problem oriented languages, interactive input, various fixed format modes, etc.), should be minimal;
- The effort required to implement various output modes (such as selected tabular output, output on 8 1/2 x 11 paper, control of intermediate computation, etc.) should be minimal.

Supporting Aspects

3.1 - A great diversity was inclinated by the state design agencies with respect to input modes important for the bridge design functions. Of these 70% specified interactive capabilities; 58% specified a preference for a problem oriented language; 50% for free format input, and 27% for fixed format.

3.2 - Diversity was also indicated by the states with respect to output. Of these, 59% wanted control of print of intermediate computations, 54% indicated graphical output (42% wanted interactive graphics), 38% indicated a preference for tabular output selected by user, and 29% wanted output on 8 1/2" x 11" paper.

3.3 - The universal language used by the state design agencies is FORTRAN. All programs identified within the Phase I effort were in FORTRAN. Over 91% of the state agencies indicated FORTRAN as the preferred language for any integrated system.

3.4 - The various state agencies are currently utilizing 7 different hardware vendors (where only 5 vendors were evident in 1974). The trend towards distributed processing and minicomputer pertains or under diversity of systems in use by design agencies.

3.5 - The AASHTO specification have changed to such a degree that a large number of the superstructure and prior programs identified are obsolete. The greatest impediment to computer utilization cited by 48% of the states is the lack of programs incorporating current design codes.

3.6 - The diversity of features specified by the various states as being major mandatory, mandatory and desired indicates that any program selected must be amenable to upgrade to include enhancements.

Requirement 4.0 - ANY APPLICATION PROGRAM MUST BE PRODUCTION ORIENTED AND MUST UTILIZE CURRENT AASHTO SPECIFICATIONS.

Supporting Aspects

4.1 - The lack of programs which incorporate current design codes is cited as the most important impediment to computer utilization by 48% of the state design agencies;

4.2 - The lack of useful production oriented bridge design programs is cited as the second most important impediment to computer utilization by 48% of the state design agencies;

4.3 - In response to the questionnaire on the design of plate girders and rolled section bridges, 66% of the state design agencies requested WSD and LFG according to AASHTO.

Proposition 5.0 - THE SYSTEM MUST CONTAIN THE MOST ADAPTABLE METHODOLOGY AND ANALYSIS TECHNIQUES.

5.1 - The requirements stipulated by the various state design agencies on the questionnaire are so broad that only the most general methodology will suffice (see Appendix C, Tables G-1 through G-23) for the Mandatory and Major Mandatory requirements).

5.2 - Experience of the research team strongly indicates that the more restricted methods such as moment distribution, slope deflection, column analogy, etc. are difficult to manage, update and program no matter how effective they were in the past.

Outlined in Table 5 - Summary of Criteria, is a restatement of each item that makes up the criteria along with a description of how each program will be evaluated relative to that item. Also tabulated within the table are the locations of the reference data which supports the evaluation method.

All programs will thus be compared to a general standard criteria. Those programs which meet, or nearly meet, the criteria will be designated as candidate programs. In the cases where the programs nearly meet the criteria, the deficiencies will be noted (see Sections 2.5, 2.6, 2.7 and 2.8).

2.5 COMPONENT SELECTION - SUPERSTRUCTURE

The superstructure design components (or modules) which are recommended for inclusion into the integrated bridge design system are given herein. The selection process itself was made particularly difficult due to the large number of programs (109) which required evaluation, and the many features which required evaluation. Great interest was shown by users in a general program which would design continuous composite/noncomposite steel beam bridges in accordance to current AASHTO LFD and WSD criteria. The needs for such a program are undoubtedly brought about by the reduced programming efforts within the state design agencies, by the complexity of the design environment, and by rapidly changing AASHTO specifications. Thus, with the user expectation high, the scope of any new program must necessarily be a global statement of all the features required by the various state design agenices.

The process in making the selection of the specific superstructure components was developed in three parts: (a) the questionnaire response where summary data describing the needs and deficiencies of the users are given; (b) the summary review of available bridge super structure design software, and (c) the selection of specific components for the proposed system. These are discussed in detail as follows:

TABLE 5 SUMMARY OF CRITERIA

CRITERIA	DETERMINATION	REFERENCE TABLES
1. The application program selected must be as general as possible with respect to overall application capabilities	1. Programs with the highest rating (which indicates the greatest capabilities) were selected as candidate programs 2. The features and deficiencies within the candidate programs were reviewed via the detailed evaluation tables and abstracts	Appendices B through E
2. The application programs selected must be adequately documented.	1. Data in the compendium were checked as to the status of the documentation 2. The documentation of the candidate programs were reviewed for completeness and content	Tables B-2 C-2, D-2, and E-2
3. The application programs selected should be written in FORTRAN and be constructed with the greatest modularity in order to readily accomodate code changes, differing I/O requirements and upgrading to include added capability	1. The documentation of the candidate programs were reviewed with respect to modularity and to the quality and modes of input and output 2. The various states which authored the candidate programs were contacted to ascertain the level of modularity contained within the programs	
4. The system must be production oriented and utilize current AASHTO specifications	1. A review of the tables in the compendium were made with respect to the specifications used 2. A review of the documentation of the candidate program was conducted with respect to the specification used and the feasibility of implementation of the code 3. A review of those states which are using the candidate program	

TABLE 5 (continued)

CRITERIA	DETERMINATION	REFERENCE TABLES
5. The system should include the most adaptable methodology	1. A review of the tables in the compendium were made with respect to the structural analysis methods used	

2.5.1 Superstructure Questionnaire Responses

The portion of the questionnaire which contained information relating to the design of bridge superstructure was the most extensive and detailed of any application area investigated. Over 80% of the total number of questions appearing in the questionnaire applied to the four superstructure construction types reviewed: continuous (or simple) beam composite and noncomposite bridges composed of open steel sections; continuous (or simple) prestressed concrete bridges; and continuous (or simple) reinforced concrete bridges. Of the 154 items evaluated in these areas, the following response was obtained:

1) All features received a Mandatory rating from at least 13% of the states;

2) 96% of the features received a Mandatory rating from at least 20% of the states;

3) 88% of the features received a Mandatory rating from at least 30% of the states;

4) 57% of the features received a Mandatory rating from at least 50% of the states.

It was concluded from above that the features specified within the superstructure portion of the questionnaire composed a statement of the global requirements for superstructure design. This, of course, was to be expected since the questions based originated both from a review of current practice and from those features contained within existing software.

Much general economic information was also developed from questionnaire data involving the nontechnical items 7.1 through 7.5 (See Exhibit F-6, Appendix F).

1. The identified and extrapolated salary costs for state design agencies involving the development and maintenance of superstructure design programs are $1,403,600 and $2,405,480 respectively. The total

extrapolated annual salary plus hardware support costs for state agenices involved in the development and maintenance of superstructure design programs is \$6,214,560 per year (see Table 4).

2. The identified and extrapolated annual salary costs for state agencies for engineering and technical staff involved in the design of bridge superstructures is \$21,368,600 and \$44,528,000 respectively (see Section 2.3.1).

3. Approximately 45% of the in-house superstructure design for state agencies is performed by computer. Overall autoimation for the superstructure application is 49% (see Table G-4 of Appendix G).

4. An upper limit for the potential salary savings for full automation for the superstructure design function is approximately \$23,154,600 per year.

Thus, the annual salary expenditures for engineers and technicians involved in program development, maintenance and design for the bridge superstructure function is quite extensive.

2.5.2 Review of Available Superstructure Software

Due to the large number of superstructure application programs, it was necessary to perform the software review in two general stages - the elimination stage and the evaluation stage. These are discussed in detail as follows:

The first (elimination) stage involved the disqualification of all programs which were low in overall application capabilities. In order to accomplish this, a minimum value for the numerical ranking was established for all application areas, such that any program which attained this ranking was designated as a candidate for incorporation into the integrated bridge design system. The limit for this ranking was set sufficiently low so as to yield the maximum number of viable programs. The specific numerical cutoff-points in the ranking

for all superstructure construction types are shown in Table 6. Here, it can be noted that a total of 20 programs have been designated as candidates with 7 pertaining to steel beam bridges, 9 to prestressed concrete bridges and 4 to reinforced concrete bridges.

Insight into the consequences of the ranking limits can be gained through a detailed review of Tables B-1 through B-10 in Appendix B and to those candidate programs given in Tables 7 and 8. Here, programs which fall below, say a ranking of 40 to 50 points, generally exhibit limitations in the features which have been specified by users as either mandatory or major mandatory. Specifically, such features relating to analysis details (such as hinges, cantilevers, etc.), loadings (AASHTO, truck and lane loadings, sidewalk loading, temperature effects, construction sequencing; load trains, recycling for updating LL envelopes, special and generalized vehicles, etc.), and design (fatigue, stiffener design, cover plate design, stresses, and the most serious - the lack of current specifications) are most often not available in programs of low ranking. The lower limit for an acceptable ranking for steel, prestress and reinforced concrete bridge types were assummed to be 40, 30 and 20, respectively (See Table 6). Programs which fall below these limits are extremely limited with respect to any general applicability.

In reviewing the global capability afforded by the 109 superstructure design programs now in use, it is discovered that the features available for general use are extremely limited. Figure 3 graphically illustrates this with the vast number of programs (84%) falling below a numerical ranking of 30%. The mean and average ranking for all superstructure programs are 19 and 20, respectively.

A further analysis indicates that almost 80% of the programs are used by one state agency only (see Figure 4). Thus, most programs are created for one specific state design criteria which is probably why so many programs exhibit limited

TABLE 6 RANKING CUTOFF CRITERIA FOR SUPERSTRUCTURE PROGRAMS

CONSTRUCTION TYPE	NUMBER OF PROGRAMS	NUMBER OF ITEMS RATED	AVERAGE PROGRAM RATING (%)	MEAN PROGRAM RATING (%)	NO. PROGRAMS WITH MINIMUM % RANKING									
					0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100
COMPOSITE/NONCOMPOSITE STEEL BEAM BRIDGE	67	83	19	18	23	15	18	4	3	1	2	0	0	1
PRESTRESSED CONCRETE BEAM BRIDGE	31	80	22	21	2	12	8	7	2	0	0	0	0	0
REINFORCED CONCRETE BEAM BRIDGE	11	61	24	18	3	4	2	1	0	0	1	0	0	0
TOTALS/Average	109	75	20	19	28	31	28	12	5	1	3	0	0	1

TABLE 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: STRUCTURAL ANALYSIS DATA

CATEGORY	NUMBER	FEATURE	STEEL OPEN SECTION							PRESTRESSED CONCRETE SECTIONS									REINFORCED CONCRETE					FEATURE STATUS
			5804 (40.2)	4301 (41.7)	1202 (43.0)	4712 (51.5)	6301 (60.8)	2705 (61.3)	2501 (91.7)	0719 (30.0)	0705 (31.3)	0802 (32.6)	3701 (34.0)	5605 (34.0)	5602 (36.8)	0715 (38.2)	6201 (40.3)	4601 (41.7)	2202 (24.3)	0716 (25.0)	1202 (43.0)	6301 (65.3)		
SIZE LIMITS	1.	Maximum number of spans =	5	8	8	8	19	5	10	5	1	1	1		1		10	7	1	8	8	14		
	2.	Maximum number of girders =																			1			
	3.	Maximum number of discrete sections/bridge =	105						150			1	1		10		1	10			10	18		
	4.	Other* (specify)																						
RELEASES	5.	Hinges anywhere on bridge		X		X		X	X							X		X						M
	6.	Shear releases anywhere on bridge		X					X															D
	7.	Other* (specify):																						
MEMBER TYPES	8.	Curved members	X																					M
	9.	Linear tapers	X	X	X		X	X	X							X		X			X	X		M+
	10.	Parabolic tapers	X	X	X		X	X	X							X		X			X	X		M+
	11.	Arbitrary tapers	X	X	X		X	X	X							X		X			X	X		M+
	12.	Flange transition	X	X	X		X	X	X	X										X	X	X		M
	13.	Truss diaphragms			X				X								X				X			M
	14.	Beam diaphragms				X	X	X				X		X	X		X					X		M
	15.	Cantilevers	X					X	X				X					X	X	X				M
	16.	Continuous slab	X		X	X	X	X	X	X				X			X				X	X		M
	17.	Other (specify)																						
LOADS	18.	Joint loads			X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		M+
	19.	Member loads	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		M+
	20.	Temperature/prestrain loads							X							X		X						N
	21.	Support settlement	X		X		X		X							X					X	X		D
	22.	Creep-shrinkage	X		X				X		X	X	X	X	X		X	X			X			D
	23.	Other* (specify):																						

TABLE 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: LOADING CAPABILITIES AND OPTIONS

CATEGORY	NUMBER	FEATURE	STEEL OPEN SECTION							PRESTRESSED CONCRETE SECTIONS									REINFORCED CONCRETE					FEATURE STATUS
			5804	4301	1202	4712	6301	2705	2501	0719	0705	0802	3701	5605	5602	0715	6201	4601	2202	0716	1202	6301		
DEAD LOADS	1.	DL moment, shears, reactions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		M+
	2.	DL deflections	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		M+
	3.	Construction staging (e.g., N = 10, 30 infinity	X		X	X	X	X	X				X		X		X				X	X		M+
	4.	Arbitrary deck sequencing							X															M+
	5.	Arbitrary DL support conditions (shoring)	X		X	X	X	X	X	X			X			X	X	X		X	X	X		D
	6.	Special DL conditions	X	X	X	X	X	X	X		X	X	X	X		X	X				X	X		M
	7.	Other (specify)																						
AASHTO LIVE LOAD ENVELOPES	8.	LL truck and lane loads	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		M+
	9.	LL deflections	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		M+
	10.	Impact	X		X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		M+
	11.	Multi-lane reduction	X		X	X	X	X	X	X			X				X	X			X	X		M+
	12.	Sidewalk	X		X	X	X	X	X								X	X			X	X		M+
	13.	Maximums on diaphragms													X									D
	14.	Other* (specify)																						
GENERAL LIVE LOAD OPTIONS	15.	Influence ordinates	X	X	X		X											X			X	X		M
	16.	Influence line plots																						D
	17.	Special trucks (standard state)	X	X		X	X	X	X					X	X	X	X	X				X		M+
	18.	Generalized trucks (input by user)	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		M+
	19.	Load trains			X		X		X	X	X			X	X	X				X	X	X		M+
	20.	Interaction for moment and shear (LFD)						X	X							X								M+
	21.	LL by AREA specifications																						D
	22.	Automatic recycling to update LL envelopes			X	X	X	X	X	X											X	X		M+
	23.	Unidirectional truck capability					X	X	X									X				X		M+
	24.	Nonfatigue LL options		X	X				X												X			M+
	25.	Specification of stress range	X		X	X	X		X								X					X		M+
	26.	Specification for impact factors	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X		M+
	27.	Specification of distribution factors	X	X	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X		M+
	28.	Other* (specify):																						

TABLE 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: GENERAL DESIGN OF PRESTRESSED CONCRETE BRIDGES

CATEGORY	NUMBER	FEATURE	CANDIDATE PROGRAMS									FEATURE STATUS
			0719	0705	0802	3701	5605	5602	0715	6201	4601	
SPECIFICATION	1.	AASHTO working stress design (WSD)	X	X	X	X	X	X	X	X	X	M+
	2.	AASHTO load factor design (LFD)										M+
	3.	Other* (specify):										
RATING	4.	Inventory and operating			X					X		M+
	5.	Permit vehicles										M
	6.	Ultimate load								X		M
	7.	Other* (specify):										
DESIGN MODES	8.	Ability to compare various designs in one pass	X						X	X		D
	9.	Recycling of updated designs	X					X	X	X		M+
	10.	Interactive design via data base				X	X					M+
	11.	Design from standard menus of section types	X		X	X	X	X	X	X		M+
	12.	Depth selection	X		X	X			X	X		M+
	13.	Section selection	X		X	X	X	X	X	X		M+
	14.	Other* (specify):										
CONSTRUCTION	15.	Pretensioned	X	X	X	X	X	X	X	X	X	M+
	16.	Posttensioned		X			X	X	X	X	X	M+
	17.	Slab	X							X		M+
	18.	"I", "T", or "box" sections	X	X	X		X		X		X	M+
	19.	Composite		X	X		X	X	X	X	X	M+
	20.	Noncomposite	X	X	X	X		X	X		X	M+
	21.	Menus of standard section			X			X				M+
	22.	Continuous for LL only	X			X	X		X	X		M+
	23.	Maximum number of spans =	5	1	1						7	
	24.	Other* (specify):										

TABLE 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: PRESTRESSED CONCRETE BRIDGE DESIGN DETAILS

CATEGORY	NUMBER	FEATURE	CANDIDATE PROGRAMS									FEATURE STATUS
			0719	0705	0802	3701	5605	5602	0715	6201	4601	
GENERAL	1.	Maximum number postensioning strand profiles = ______										
	2.	Maximum number prestressing strand profiles = ______										
	3.	Calculates optimal number of steel strands	X			X				X		M+
	4.	Draped strands	X	X	X	X	X	X	X	X	X	M+
	5.	Straight strands	X	X	X	X	X	X	X	X	X	M+
	6.	Partial length tendons							X		X	M+
	7.	Multiple cable paths	X	X		X	X	X	X		X	M+
	8.	Arbitrary cable paths		X				X	X		X	M+
	9.	Left or right anchor set	X	X					X		X	U
	10.	Debonding							X			M+
	11.	Friction due to drape	X	X	X		X		X		X	M+
	12.	Friction due to wobble	X	X					X		X	M+
	13.	Friction due to curvature	X	X					X		X	M+
	14.	Utilizes transferred sections	X	X	X	X		X				M
	15.	Gives all section properties	X	X	X	X	X	X	X	X	X	M+
	16.	Completely arbitrary section properties						X	X	X		M+
	17.	Frame action for prestressed and reinforced concrete member					X		X	X		M+
	18.	Calculation of stirrup spacings	X	X		X	X	X	X			M+
	19.	Other * (specify): ______										
STRESSES	20.	Top of slab	X	X	X		X	X	X	X	X	M+
	21.	Top of beam	X	X	X	X	X	X	X	X		M+
	22.	Bottom of beam	X	X	X	X	X	X	X	X	X	M+
	23.	Calculation for service conditions and transfer	X	X	X	X	X	X	X	X		M+
	24.	Other * (specify). ______										

TABLE 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: GENERAL DESIGN OF REINFORCED CONCRETE BRIDGES

CATEGORY	NUMBER	FEATURE	CANDIDATE PROGRAM				FEATURE STATUS
			2202	0716	1202	6301	
SPECIFICATION	1.	AASHTO working stress design (WSD)	X	X	X	X	M+
	2.	AASHTO load factor design (LFD)	X				M+
	3.	Other* (specify):					
RATING	4.	Inventory and operating				X	M+
	5.	Permit vehicles				X	M+
	6.	Ultimate load				X	M+
	7.	Other* (specify):					
DESIGN MODES	8.	Ability to compare various designs in one pass		X			M+
	9.	Recycling of updated designs		X		X	M+
	10.	Interactive design via data base	X			X	M+
	11.	Design from standard menus of section types	X	X		X	M+
	12.	Depth selection	X			X	M+
	13.	Section selection	X	X		X	M+
	14.	Other* (specify):					
CONSTRUCTION	15.	Slab bridge		X	X	X	M+
	16.	Rectangular, T, individual box, connecting boxes	X	X	X	X	M+
	17.	Composite	X			X	M
	18.	Continuous for LL only			X		M
	19.	Maximum number of spans =	1	8	8	6	
	20.	Multiple construction types (specify):					NR
	21.	Other* (specify):					

TABLE 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: REINFORCED CONCRETE BRIDGE DESIGN DETAILS

CATEGORY	NUMBER	FEATURE	CANDIDATE PROGRAMS 2202	0716	1202	6301	FEATURE STATUS
GENERAL	1.	Utilizes transformed section (compression steel)			X	X	M
	2.	Calculation of stirrup spacing	X	X		X	M+
	3.	Gives all section properties		X	X	X	M+
	4.	General fy for rebar	X	X	X	X	M+
	5.	Calculates required bar lengths	X	X			M+
	6.	Modification for shear diagram to satisfy AASHTO 1.5.13(A)(6)					M+
	7.	Provides the (moment capacity)/(shear) curve per 1.5.13(B)(3)					M+
	8.	Computes permissible shear stress AASHTO 1.5.35 (B)(2) or (3) for LFD and AASHTO 1.5.29(B)(2) or (3) for WSD (M & V interaction)	X	X			M+
	9.	Crack control check (AASHTO 1.5.39–LFD)	X	X		X	M+
	10.	Fatigue limits for LFD and WSD					M+
	11.	Other* (specify):					
STRESSES	12.	Top of slab		X	X	X	M+
	13.	Top of beam	X	X	X	X	M+
	14.	Bottom of beam	X	X	X	X	M+
	15.	Rebar stress check (to determine whether WSD or LFD is most economical		X	X	X	M
	16.	Other* (specify):					

TABLE 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: GENERAL DESIGN OF STEEL SECTION BRIDGES.

CATEGORY	NUMBER	FEATURE	CANDIDATE PROGRAMS 5804	4301	1202	4712	6301	2705	2501		FEATURE STATUS
SPECIFICATION	1.	AASHTO working stress design (WSD)	X	X	X	X	X	X	X		M+
	2.	AASHTO load factor design (LFD)				X		X	X		M+
	3.	Other* (specify):									
RATING	4.	Inventory and operating rating					X		X		M+
	5.	Permit vehicles					X		X		M
	6.	Ultimate load					X		X		M
	7.	Other* (specify):									
DESIGN MODES	8.	Ability to compare various designs in one pass		X		X	X		X		M
	9.	Recycling of updated designs	X	X		X	X	X	X		M+
	10.	Interactive design via data base	X	X			X		X		M+
	11.	Design from preset configurations (such as cover plates over negative moment areas only)	X	X		X	X	X	X		M+
	12.	Depth selection	X	X		X	X	X	X		M+
	13.	Section selection	X	X		X	X	X	X		M+
	14.	Other* (specify):									
CONSTRUCTION	15.	Composite	X		X	X	X	X	X		M+
	16.	Noncomposite		X	X	X	X	X	X		M+
	17.	Plate girders		X	X	X	X	X	X		M+
	18.	Rolled sections	X	X	X	X	X	X	X		M+
	19.	Hybrid sections		X		X	X				M+
	20.	Other* (specify):									

TABL 7 FEATURE SUMMARY FOR CANDIDATE PROGRAMS: DESI DETAILS OF STEEL SECTION BRIDGES

CATEGORY	NUMBER	FEATURE	CANDIDATE PROGRAMS 5804	4301	1202	4712	6301	2705	2501	
COVER PLATES	1.	Envelopes			X	X			X	M
	2.	Automatic development of cut-off points	X	X			X	X	X	M+
	3.	Variable cover plate transition	X	X	X		X	X	X	M+
	4.	Other* (specify):								
FATIGUE	5.	All stress categories covering all details		X	X	X			X	M
	6.	Nonfatigue options		X	X	X			X	M+
	7.	Other* (specify):								
TRANSVERSE STIFFENERS	8.	Automatic placement		X		X	X	X	X	M+
	9.	Design of stiffener section		X		X	X	X	X	M+
	10.	Moment and shear interaction (LFD)				X		X	X	M+
	11.	Stress interaction (WSD)				X	X	X	X	M+
	12.	Other* (specify):								
LONGITUDINAL STIFFENERS	13.	Automatic placement		X		X		X	X	M+
	14.	Design of stiffener section		X		X		X	X	M+
	15.	Placement anywhere on section		X		X		X	X	M+
	16.	Other* (specify):								
SHEAR CONNECTORS	17.	Studs			X	X		X	X	M+
	18.	Angles			X				X	M+
	19.	Composite				X		X	X	M+
	20.	Noncomposite			X	X		X	X	M+
	21.	Partial composite over negative moment regions				X			X	M+
	22.	Other* (specify):								
STRESSES	23.	Actual/allowable stress top/bottom flange	X	X	X	X	X	X	X	M+
	24.	Actual/allowable range in web	X	X	X		X	X	X	M+
	25.	Concrete deck stresses	X		X	X	X	X	X	M+
	26.	Rebar stresses			X	X	X		X	M+
	27.	Other* (specify):								
LOAD FACTOR DESIGN	28.	Automatic placement of bracing						X	X	M+
	29.	Moment and shear interaction for bracing							X	M+
	30.	20% increase due to moment gradient						X	X	M+
	31.	10% reduction in negative moment region						X	X	M+
	32.	Automatic interpolation in transition regions							X	M+
	33.	Other* (specify):								

TABLE 8 OVERALL RATING FOR CANDIDATE SUPERSTRUCTURE PROGRAMS

CONSTRUCTION TYPE	INDEX NO.	CALL NAME	PROGRAM USAGE: NUMBER OF ORGANIZATIONS		PROGRAM USAGE: NUMBER OF STAFF		DOCUMENTATION PROVIDED	TOTAL RATING OF FEATURES					
			LIGHT USAGE	HEAVY USAGE	LIGHT USAGE	HEAVY USAGE		ANALYSIS	LOADINGS	DESIGN DATA	DESIGN DETAILS	TOTAL OVERALL PROGRAM RATING	OVERALL RATING BASED ON 100%
STEEL OPEN SECTION	5804						S	15	19	33	15	82	40.2
	4301						S	13	6	24	42	85	41.7
	1202						S	18	22	12	36	88	43.0
	4712		2		87		S	11	16	30	48	105	51.5
	6301						S	17	26	42	39	124	60.8
	2705						S	26	29	30	45	125	61.3
	2501						S	33	30	42	82	187	91.7
PRESTRESSED CONCRETE BEAM	0719		2		39		S	0	7	18	18	43	30.0
	0705						S	7	8	12	18	42	31.3
	0802						U	2	8	25	12	47	32.6
	3701						U	8	15	11	15	49	34.0
	5605						S	8	9	16	16	49	34.0
	5602						S	8	13	16	16	53	36.8
	0715						S	22	9	12	12	55	38.2
	6201		2		29		U	2	20	29	12	58	40.3
	4601		1	1	12	37	S	21	15	12	12	60	41.7
REINFORCED CONCRETE	2202		1	1	15	15	S	7	1	18	9	35	24.3
	0716		2		27		S	0	3	15	18	36	25.0
	1202		3	3	62	71	S	18	23	15	12	68	47.2
	6301						S	17	26	33	18	94	65.3

capability. Also, most of the software, which received a lower ranking were found to be vintage programs which were written for the 2nd (circa IBM 1620) and early third (circa IBM 7090 series) generation hardware. Thus, the methodology and program structure contained within these programs were severely limited.

The second stage of the software review involved the evaluation of the candidate programs with respect to the five item criteria developed in Section 2.4. Those programs which entirely meet all items specified in this criteria are reclassified as recommended programs. Thus, the candidate programs are those which exhibit the highest overall ranking with respect to application features. The recommended programs are those which meet the criteria, are implementable for general usage.

Given in Tables 9, 10, and 11 is a comparison of all candidate superstructure design programs with the five point criteria. In order to gain insight into the basis upon which some programs were selected or rejected, the reader is directed to review Tables 6 and 7 for a comparison of application features available within the candidate programs, and the abstracts (presented in Appendix I) which describe each program in some detail. Also, in order to provide a terse explanation of the status of each program with respect to the criteria, the following is offered:

TABLE 9 SUMMARY CRITERIA COMPARISON FOR CANDIDATE PROGRAMS - REINFORCED CONCRETE BEAM BRIDGE

CRITERIA	CANDIDATE PROGRAMS			
	2202 (LOUISIANA)	0716 (CALIF.)	1202 (GEORGIA)	6301 (BRASS)
CRITERIA: The application programs selected must be as general as possible with respect to overall application capability. EVALUATION: Overall rating score.	24.3	25.0	43.0	65.3
CRITERIA: The application programs selected must be adequately documented. EVALUATION: SATISFACTORY OR UNSATISFACTORY	S	S	S	S
CRITERIA: The application program should be written in FORTRAN and be constructed with the greatest modularity in order to readily accomodate code changes, upgrades and different I/O requirements. EVALUATION: FORTRAN, MODULAR	FOR MOD	FOR	FOR -	FOR MOD
CRITERIA: The system must be production oriented and utilize current AASHTO specifications. EVALUATION: PRODUCTION, CURRENT CODE	P	P -	P -	P -
CRITERIA: The system should include the most adaptable methodology. EVALUATION: SATISFACTORY OR UNSATISFACTORY	S	S	S	S

TABLE 10 SUMMARY CRITERIA COMPARISON FOR CANDIDATE PROGRAMS - PRESTRESSED CONCRETE BEAM BRIDGE

CRITERIA	CANDIDATE PROGRAMS								
	0719 (CALIF.)	0705 (CALIF.)	0802 (COLORADO)	3701 (N. MEX)	5605 (TEXAS)	5602 (TEXAS)	0715 (CALIF.)	6201 (WISCON.)	4601 (OREGON)
CRITERIA: The application programs selected must be as general as possible with respect to overall application capability. EVALUATION: Overall rating score.	30.0	31.3	32.6	34.0	34.0	36.8	38.2	40.3	41.7
CRITERIA: The application programs selected must be adequately documented. EVALUATION: SATISFACTORY OR UNSATISFACTORY	S	S	U	U	S	S	S	U	S
CRITERIA: The application program should be written in FORTRAN and be constructed with the greatest modularity in order to readily accomodate code changes, upgrades and different I/O requirements. EVALUATION: FORTRAN, MODULAR	FOR	FOR	FOR	FOR	FOR	FOR	FOR	FOR	FOR
CRITERIA: The system must be production oriented and utilize current AASHTO specifications. EVALUATION: PRODUCTION, CURRENT CODE	P	P	P	P	P	P	P	P	P
CRITERIA: The system should include the most adaptable methodology. EVALUATION: SATISFACTORY OR UNSATISFACTORY	S	S	S	S	S	S	S	S	S

TABLE 11 SUMMARY CRITERIA COMPARISON FOR CANDIDATE PROGRAMS - COMPOSITE/NONCOMPOSITE STEEL BEAM BRIDGE

CRITERIA	CANDIDATE PROGRAMS						
	5804 (VERMONT)	4301 (OHIO)	1202 (GEORGIA)	4712 (SIMON)	6301 (BRASS)	2705 (MICHIGAN)	2501 (MARYLAND)
CRITERIA: The application programs selected must be as general as possible with respect to overall application capability. EVALUATION: Overall rating score.	40.2	41.7	43.0	51.5	60.8	61.3	91.7
CRITERIA: The application programs selected must be adequately documented. EVALUATION: SATISFACTORY OR UNSATISFACTORY	S	S	S	S	S	S	S
CRITERIA: The application program should be written in FORTRAN and be constructed with the greatest modularity in order to readily accomodate code changes, upgrades and different I/O requirements. EVALUATION: FORTRAN, MODULAR	FOR MOD	FOR MOD	FOR -	FOR	FOR MOD	FOR -	FOR MOD
CRITERIA: The system must be production oriented and utilize current AASHTO specifications. EVALUATION: PRODUCTION, CURRENT CODE	P -	P -	P -	P CC	P -	P CC	P CC
CRITERIA: The system should include the most adaptable methodology. EVALUATION: SATISFACTORY OR UNSATISFACTORY	U	U	U	U	U	S	S

STEEL OPEN SECTION BRIDGE DESIGN PROGRAMS

2501 - The Maryland SHA Bridge Design, Rating and Routing System

The Maryland Bridge Design, Rating, and Routing System attained the highest overall ranking (187 or 91.7% of the features reviewed) of any program reviewed. The important attributes of the system are that it is extemely modular, is current with respect to both the AASHTO, WSD and LFD criteria and is being considered for adoption by 9 state agencies (a more detailed description of the design portion of the program is offered in the next section). The deficiencies are that it does not perform a design on reinforced or prestressed concrete bridges or on hybrid steel sections, nor has the LFD portion of the program experienced a great deal of productive use. This program has been designated as a recommended program.

2705 - Michigan Bridge Design Program

The Michigan ranked second in overall capability (125 or 61.3% of the features), just below the Maryland system. The program has excellent applicatin capabilities and is current with the AASHTO, WSD and LFD specifications. The limitations include the nongenerality of various LL options (e.g. no local trains) the inability to perform a bridge rating, and certain deficiencies in LFD options. The major problem seems to be that the program is poorly documented and is not modular in construction. These have kept the program from attaining the recommended category.

6301 - Bridge Rating and Analysis Structural System (BRASS)

The BRASS system, written by the Wyoming Highway Department, attained the third highest ranking (124 or 60.8% of the features) of those programs reviewed. The important attributes of the program are that it is

modular, and extremely diverse in capability with respect to the types of bridge structures it can handle. However, the program is not up to the current AASHTO, WSD or LFD specifications. Moreover, it is felt that the methodology utilized for structural analysis would make it extremely difficult to upgrade it to current codes. These limitations have kept the program from becoming a recommended program.

4712 - Continuous Beam Analysis and Design (SIMON)

The SIMON program was developed by United States Steel Corporation for the design of plate girder bridges using either WSD or LFD methods. The basis of the program is the Wisconsin Continuous Beam Analysis and Design Program which has been an extremely popular program throughout the year. However, the program is not modular and would be extremely difficult to modify in order to incorporate the general mandatory and major mandatory features required. Other limitations are also evident as can be noted in Tables 7 and 8. For these reasons, the program is not recommended.

1202 - The Analysis of Continuous Beams for Highway Bridges (Georgia)

This very excellent program was written by Georgia DOT and has been used collectively by more states than any other bridge design program. The program was scheduled for updating by Alabama DOT for WSD and inclusion of LFD under the Southern Area AASHTO cooperative effort. However, the program effort was cancelled in lieu of a review of the Maryland System for a possible replacement. The major limitation (besides those in overall capability which can be noted in Tables 7 and 8), is that the program is not up to the current AASHTO specifications, and is not modular. For these reasons, it is not recommended.

4301 - System for the Optimum Design of Highway Bridges

The Ohio optimum beam design program was written at Case Western Reserve University for Ohio DOT to produce a practical design for noncomposite bridge structures based upon actual costs. Although the program does not contain many of the mandatory or major mandatory features required, it is felt that the optimum beam design approach warrants special consideration in future development. Unfortunately, the program does not meet the current AASHTO code, does not contain LFD nor does it perform a design for composite structures. Because of these severe limitations, the program is not recommended.

5804 - Vermont Department of Highways Continuous Span Series

The Vermont bridge design program represents an excellent basic design program for highway bridges. Unfortunately, the program does not include the current AASHTO specifications nor does it contain a LFD option. Many other features are also missing (see Tables 7 and 8) including a lack of modularity, and an analysis method (moment distribution and column analogy) which lacks generality. For these reasons, the program is not recommended.

Thus, the only steel open section bridge design program that meets all five items of the criteria is the Maryland SHA Bridge Design, Rating, and Ranking System. Again, the system has fared so well with respect to the criteria because it was specifically developed from a very similar set of requirements. Due to the broad nature of the survey conducted herein for Phase I, it was impossible to describe all of the features available within the modular Maryland System. These can be reviewed in detail in the documentation (or systems manual) describing the system.

PRESTRESSED CONCRETE BRIDGE DESIGN PROGRAMS

0719 - Design of Prestressed Concrete Box Girder Bridges (California)

This system attained a ranking of 30%, the lowest of the candidate programs. The program uses a general analysis technique (stiffness method) and produces good designs for limited structural configurations using an optimization technique. The program, however, does not consider discontinuities in strand profiles and is limited to cast-in-place post-tensioned systems. For these reasons, it has not attained the recommended category.

0705 - Prestressed Girder Analysis (California)

This system attained a ranking of 31%, just above the California system. The capabilities of this program include both pretensioned and post-tensioned construction. However, the structural system considered is limited to simple span bridges. Moreover, the program is generally not modular in construction. These reasons have kept the program from attaining the recommended category.

0802 - Prestressed Concrete Girder Design (Colorado)

This design system provides good designs for limited structural configurations, and does perform the important task of determining the Inventory and Operating rating of simple span I-beam bridges. However, the program lacks genrality, is poorly documented and is generally not modular in construction. These limitations have kept the program from becoming a recommended system.

3701 - Prestressed Concrete Beam Design (New Mexico)

This system developed by the New Mexico State Highway Department attained a ranking of 34%. The program's design capabilities are general in their capabilities. However, program analysis employs moment distribution and it is felt that this methodology is not generally adaptable for system

implementation, particularly since documentation is weak and the program's construction is generally not modular. For these reasons, the program is not recommended for implementation.

5605 - Design of Continuous Prestressed Beams (Texas)

This system, developed at the Texas Transportation Institute, yields satisfactory designs for a continuous prestress system composed of prismatic I-beam sections. Although many of the program's features are general in application, the program is not modularly constructed. Implementation of this program into the integrated system may be quite difficult. For this reason, the program has not attained the recommended status.

5602 - Design of Prestressed Concrete Girders (Texas)

This system is ranked fourth (36.8%) among the candidate programs, and is an excellent design system for simple span prestressed concrete bridges. It is felt that this system, although not directly applicable to a continuous beam system, warrants special consideration for inclusion into the integrated system. The program has seen much production use, employs current AASHTO specifications and is modular in construction. This program is therefore designated as a recommended program.

0715 - Analysis of Prestressed Concrete Box Girder Bridges (GIRDER PC)

This California system attained the third highest ranking (55 or 38.2% of the features) of those programs reviewed. The important attributes of the program is that it is modular and is extemely diverse with respect to the types of bridge structures it can handle. The program employs the stiffness matrix analysis method which further enhances the adaptability of the program into the integrated system. A review of the program's features in the detailed abstract supports the designations of this system as a recommended program.

6201 - Prestressed Concrete I-Girder Design (Wisconsin)

This program attained the second highest ranking (58 or 40.3%) of the features) of those programs reviewed. This system employs current code and performs the bridge rating function. Although the program is a generally satisfactory design system, it is not modular in construction and is unsatisfactorily documented. For these reasons the program has not attained the recommended status.

4601 - Analysis of Prestressed Concrete Bridges (Oregon)

This bridge analysis system attained the highest ranking (60 or 41.7% of the features) of those programs reviewed, and represents an excellent prestressed girder analysis program. However, there are two primary drawbacks in this system. First, it is limited to prismatic girders (which could be corrected) and second, it is not modularly constructed. Despite the fact that a plane frame analysis is employed (making the analysis method system compatible) it is felt that modification of this program for system incorporation would prove too difficult. For this reason it is not a recommended program.

Thus, it is seen that none of the prestressed concrete bridge programs completely satisfies all five items of the criteria and is superior to the other programs reviewed. Indeed, from this review it is clear that prestressed concrete bridge systems are very state oriented, and that a distinct separation of these systems according to their analysis/design ability and to their adaptability into general usage would require a more detailed analysis than was conducted here. However, two systems, the Texas Prestressed Concrete Girder Design Program and the California Prestressed Concrete Box Girder Analysis Program are recommended for general usage. Together these programs form a solid basis upon which a general purpose prestressed concrete sybsystem could be developed.

REINFORCED CONCRETE BRIDGE DESIGN PROGRAMS

2202 - Analysis and Design of Reinforced Concrete Girders (Louisiana)

This system is an excellent analysis/design program for simple span reinforced concrete bridges. It is a very well documented, generally modular program, that was developed as part of the SAASHTO effort to develop bridge software. Although the lack of generality with respect to the structural configuration considered eliminates this program from overall incorporation into the integrated system, it is felt that this modular system warrants additional consideration in future development.

0716 - Design of Reinforced Concrete Box Girder Bridges (California)

This system, although primarily developed for analysis and design of California's reinforced concrete box girder bridges, it is generally applicable to reinforced concrete I-beam sections as well. The program's attributes include current code provisions, modular construction and a dynamic procedure for optimizing reinforcement layout. For these reasons, this system is designated as a recommended program.

1202 - The Analysis of Continuous Beams for Highway Bridges (Georgia)

This system has seen much use for both steel and reinforced concrete bridge analysis. As can be seen in tables 7 and 8, the program is quite general in its reinforced concrete analysis capability. The major drawbacks, however, are that the program is lacking in current AASHTO code provisions and is not modularly constructed. These limitations prevent this system from attaining the recommended status.

6301 - Bridge Analysis and Rating System (BRASS)

This system recieved the highest ranking (94 or 65.3% of the features) of the reinforced concrete bridge programs reviewed. The outstanding features of this system include its ability to perform both analysis and design, and the generality of the structural configurations considered (see Tables 7 and 8). Moreover, BRASS contains current WSD and LFD provisions for reinforced concrete and is highly modular. Thus, this system has been designated as a recommended program.

Thus, two reinforced concrete bridge design programs are recommended for implementation into the integrated bridge design system. Although the California program did not receive an outstanding ranking (36 or 25% of the features), it is felt that several worthy components (reinforcement optimization, for example) of this modular system can readily be coupled with various analysis/design modules from BRASS. Together these form a very satisfactory reinforced concrete bridge analysis and design module.

2.5.3 Superstructure Application Candidates

The procedures used to select the components for the superstructure portion of the integrated bridge design system fell into two levels of activities. The first level required a full definition of all modules relating to all construction types considered. These are given in Table H-1 of Appendix H where two types of modules are shown. The first micro-module level consists of the smallest practical unit which can be created within a program such that only one application task or activity is performed. An example of this type of module is represented by B2002 - Computation of Fixed-End-Moments. Here all fixed-end-effects are computed for internal member loads for incorporation into the load vector. As can be noted from Table H-1, B2002 appears many times throughout the systm (e.g.

in BDS 02, BDS 12, BDS 21, in BDS 23, BDS 29, BDS 30, BDS 31 for DL and LL computations in steel and concrete structures). Thus, the micro-modules perform the most basic level computations in the most general manner.

The second macro-module level consists essentially of an entire activity such as BDS 22 - Live Load Computations for Moment in Composite Steel Girder Bridge. Here, various micro-modules such as B4002, B2004, B2008, B2006, B2002, and B25002 would be incorporated into the LL macro module. However, it should be noted that the macro-module need not be made up of micro-modules, but could be composed of one main-line link, overlay, root segment, etc.

Thus, the modular concept allows two definitions - the micro and macro level modules. Traditionally, both levels have been used throughout the years. TIES (for Total Integrated Engineering System) for example, was based upon the macro-module concept with the modules being those analysis methods most preferred by each state. However, the trend is definitely towards the micro-module which affords the following advantages:

- The programs constructed of micro-modules are the most code independent in that each function is localized. Of course, no program is truly code independent, but it is much easier to modify generalized modules than large sections of code. (For example, if the distribution factor were to change in the AASHTO specification, only the micro-module B4002 would need be changed where this subroutine appears 7 times throughout Table H-1 of Appendix H).

- Since the modules are used in various different applications and types of structures, they receive more attention and tend to be more generalized and bug free. For example, the analysis module B5002 for continuous beam computations is used six times throughout the system. When a module such as this is implemented for one part of the system, it is available for use in other areas as well. Each

application use made of the module brings a greater generality and verification.

- The individual micro-modules function as a library of routines that can be used very easily in other programs and applications (the macro-module does not lend itself to this feature). The modules should be internally documented, standardized with respect to input/output and may be used in a re-entrant mode (if the operating system will allow). The Maryland system consists of such modules, they being indexed with respect to application and function (thus the numbering system B5002, etc.).
- Documenting and developing any system is made easier if it is composed of micro-modules.

Notwithstanding these advantages, the definition of modules are specified herein for both the micro and macro types. This was done so that the selection of components would allow consideration of the maximum number of systems. It is conceivable, indeed probably, that the final system would contain modules of both the micro and macro types since many excellent programs exist in both these forms.

Shown in Figure 5 is the macro flow diagram for an integrated bridge superstructure design system. The various macro-modules are given with the BDS (Bridge Design System) designation. An example of such a module would be BDS 22 - LL Moment Computation. As can be noted in Table H-1, BDS 22 consists of eight micro-modules some of which are code dependent (e.g. B4004 for AASHTO lane and truck loadings) and some of which are analysis dependent (e.g. B5002 for the computation of joint deflections, member end actions and reactions). Thus, any macro-module would probably contain a mix of analysis and specification making them extremely difficult to modify. However, some excellent programs are constructed in this manner and, indeed, consist of macro-

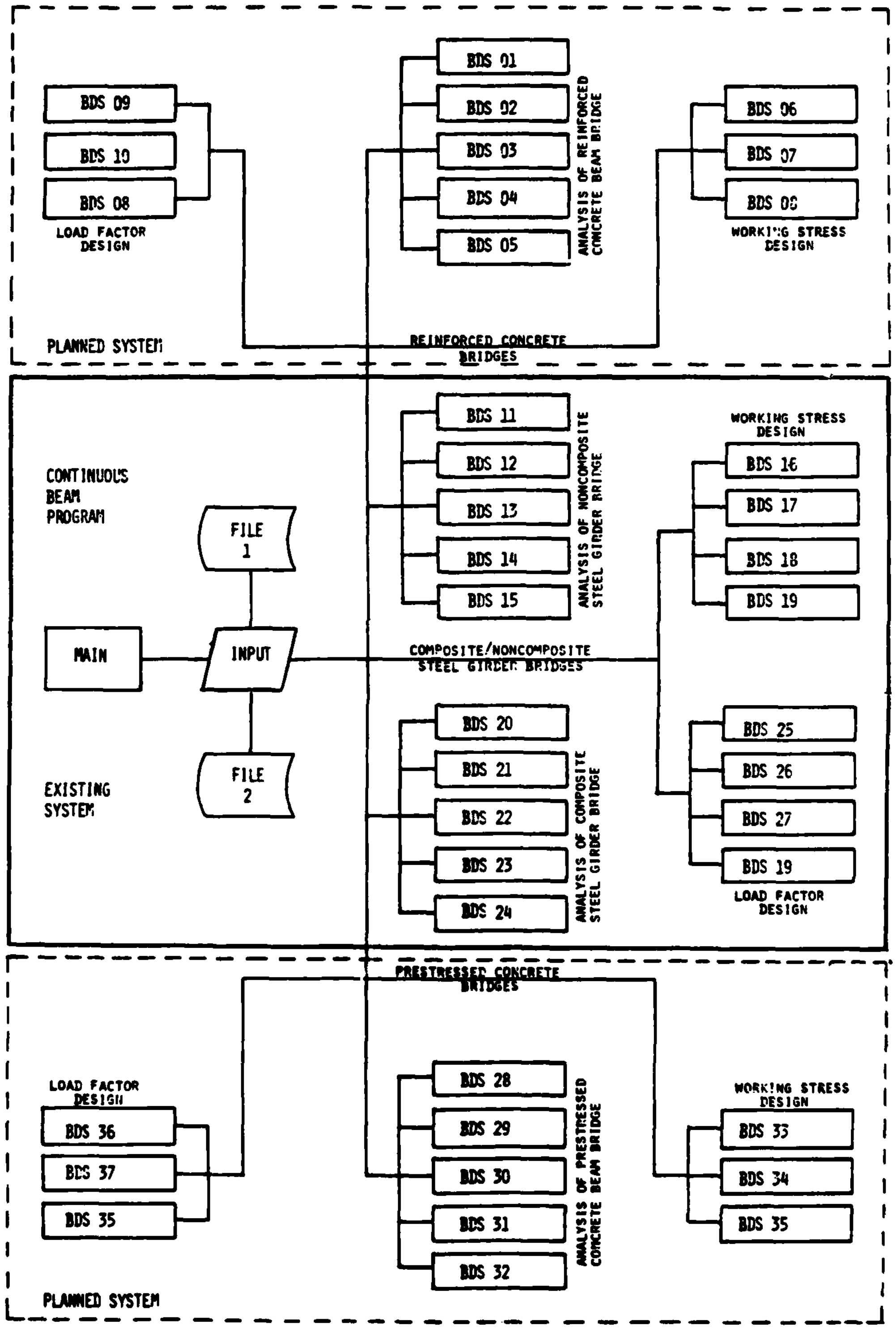

FIGURE 5 MACRO FLOW-DIAGRAM FOR INTEGRATED BRIDGE DESIGN SYSTEM

modules which are as modular as practicable for that application. A case in point would be the candidate programs which perform a design for prestressed girder pridges. Here, the application often involves simple-span bridges only. This, coupled with the proclivity of each state to specify standard strand patterns and shapes unique to that state makes the macro-module approach somewhat viable. However, this is in lieu of the apparent inability of the states to define global requirements for prestressed girder bridges and to develop a system whereby all cases can be handled. In any event, in cases where the analysis requirements are minimal, and where the design absolutely specialized, macro-modules should be considered if adequate programs are available to create these modules.

In summary, the definition of the macro and micro modules which compare the integrated bridge design system are given in Figure 5 and Table H-1 of Appendix H, respectively. This allows for the greatest flexibility in the selection of existing components. However, systems which are composed of micro-modules afford the greatest flexibility, portability and code independence and should be favored over those which are constructed as large macro-units.

The second level of activity required for the selection of components involves the matching by various modules specified above with existing modules. It must be pointed out at the outset, that no two programs which have been developed for production usage under a different design and hardware environment by different programmers will be initially compatible. This is true even of program which are highly modular in construction. In general, the programs will be minimally incompatible with respect to the following items:

1. Input and output
2. Files and file structure
3. General program flow in the main line (with respect to such items as COMMON, large program loops, etc.)

In addition to these, many other incompatabilities will undoubtedly also exist. However, if the programs that are to be joined are truly modular and adequate design programs, then it is possible to integrate them in a cost effective manner into an effective system.

Shown in Table H-1 of Appendix H, Definition of Modules for Integrated Bridge Design System and in Figure 5, Macro-Flow Diagram for an Integrated Bridge Design System, are those modules which currently exist and those which are planned. That portion which exists is composed of the Maryland SHA Bridge Design, Rating and Ranking System for composite and noncomposite steel bridges under the AASHTO working stress and load factor design methods. Here, micro modules are available, if required, for reinforced concrete, prestressed concrete, box girders, etc. as well as for steel girder bridges. As was stated previously, the Maryland system was constructed specifically to be expanded and to interface with other applications. Also, the modules are general to the degree that they can be used in part or in total (LL for example) either to augment existing systems or to form the basis of new programs. For this reason, and the high ranking the system attained in the evaluation as well as the fact that it was the only system which met the general five item criteria, the Maryland System is recommended as that system which will form the basis of the superstructure system. The manner in which other construction types will interface with the overall system will now be outlined.

1. Those programs which are recommended for use within the integrated bridge design system will be evaluated as to how their component parts can be restructed into modules generally as defined in Figure 5 and Table H-1 of Appendix H.

2. If more than one program proves viable with respect to implementability and application capability, then a detailed analysis of all systems will be done to determine the best and most cost effective route.

3. A full subsystem definition will be done which would include the following:

   a) All Input/Output
   b) All file and file structures
   c) All modules
   d) All data flow in the form of flow diagrams
   e) A preliminary version of the final documentation describing all features of the program
   f) An estimate of the time and cost required to complete the subsystem.

The specific subsystems which would be considered for the prestressed concrete and reinforced concrete construction types are given as follows:

Prestressed Concrete Subsystems

1) Texas Prestressed Girder Design (5602)
2) California Prestressed Concrete Box Girder Analysis (0715)

Reinforced Concrete Subsystems

1) Bridge Rating and Analysis System - BRASS (6301)
2) California Reinforced Concrete Box Girder Design (0716)

2.6 COMPONENT SELECTION - GEOMETRY

The initial mailing to state highway engineers requesting documentation produced documentation for twenty-five geometry application programs. The documentation was entirely user documentation with 24% of the documentation best described as minimal. After reviewing the available documentation for the programs, a set of global feature requirements was established.

The global features requirements were obtained by using the union of the primary features of all the reviewed documentation. A list of the global features for geometry is provided in the geometry section of the questionnaire (See Exhibit F-6 of Appendix F). Each program was eventually compared with the global requirements. The global requirements were also used in the questionnaire that was mailed to all state and provincial agencies. The questionnaire is presented in Appendix F, Exhibit F-6.

2.6.1 <u>Geometry Questionnaire Response</u>

Thirty-two state and provincial agencies and twenty-five private consultants responded to the bridge geometry portion of the questionaire. An evaluation of the responses revealed that approximately 58.4% of the bridge geometry applications were automated. Data used to compute this value is summarized in Table G-4 of Appendix G. The low percentage of automation is attributed to the ease of calculations cost effective and also to inadequacies in the existing bridge geometry software.

Of the thrity-six global feature requirements established for program evaluations, the responses from the state and provincial using the rating scheme (M+, M, D, NR) presented in Section 2.4 produced the following results:

1) 11 (31%) of the global requirements were major mandatory (M+),
2) 20 (56%) of the global requirements were mandatory (M),
3) 4 (11%) of the global requirements were desirable (D), and
4) 1 (3%) of the global requirements were not required.

The specific items in each category above are summarized in Tables G-14 and G-15 of Appendix G along with an indication of the evaluation (Feature Status) of each requirement. In reviewing the responses in Table G-14 of Appendix G, the responses to requirement 9, integration of bridge geometrics with an automatic graphics system, were of particular interest. Only 12% of the respondees indicated that it was desirable. This response indicates that computer graphics with bridge geometrics is a feature to be considered beyond Phase II of the subject study. In summary, 87% of the global requiremens were evaluated to have mandatory (M) or major mandatory (M+) feature status. Therefore, the global requirements provide an adequate basis to be used for evaluating each program.

2.6.2 Review of Available Geometry Software

Each of the twenty-five geometry programs was evaluated using the previously established global requirements. The results of the evaluation for each program are presented by index number in Tables C-1 to C-4 of Appendix C. The results presented in Tables C-1 to C-4 were initially determined from the provided documentation. The results of the initial evaluation were then enclosed in the questionnaire booklet and mailed to the state that provided the program documentation. The changes, if any, made by the states were then incorporated in the evaluations presented in Tables C-1 to C-4. A cross reference of the index number, program sources, and agencies are presented in Table A-3. For Tables C-3 and C-4, the feature status for each requirement is indicated at the bottom of the table.

Based on the evaluation of the program and the ability of the program to satisfy the designated feature status, a point value was assigned for each feature that the program was able to sastisfy. The point value was determined using the method presented in Section 2.4. The geometry feature evaluations were then summarized in the following categories: general capabilities, generation of cross section geometry, and generation of lines. The point value assigned to each program under each of the above categories is presented in Table C-5. The total points and percentage of total points are summarized in Table C-6. In addition, the program usage and quality of the provided documentation are presented in Table C-6. The five programs with the highest point values and adequate documentation are summarized again in Table 12.

2.6.3 Geometry Application Candidates and Description

Using the criteria discussed in Section 2.4, the programs were reviewed to determine the best candidates for future study and for possible incorporation into the system in Phase II of the study. Since time and cost limitations prevent in-depth studies of the five highest rated programs presented in Table

TABLE 12. SUMMARY OF GEOMETRY PROGRAM USAGE AND RATING

INDEX NO.	CALL NAME	PROGRAM USAGE				DOCUMENTATION	RATING OF FEATURES					COMMENTS
		NUMBER ORGANIZATIONS		NUMBER STAFF								
		LIGHT USAGE	HEAVY USAGE	LIGHT USAGE	HEAVY USAGE		GENERAL CAPABILITIES	CROSS SECTIONS	LINE GENERATION	OVERALL TOTAL RATING	OVERALL RATING BASED ON 100%	
1301	GA	1	2	1	67	S	21	12	36	69	82	
2101	SA2001	0	1	0	4	S	33	12	18	62	74	
2702	SA2501	1	0	104	0	S	25	3	21	49	58	
4701	SA4304	2	0	9	0	S	33	9	0	42	50	
2301	SA2201	0	1	0	15	S	30	0	9	39	46	
POSSIBLE							36	12	36	84	100	

12, the top three programs were evaluated using the final selection criteria outlined in Section 2.4. The results of this evaluation are presented in Table 13. The three most highly rated candidates as presented in Table 13 are:

1. "The Geometry Solution of Highway Bridges", Georgia Department of Transportation, Report Index number 1301.
2. "BELEV", Kentucky Department of Transportation, Report Index number 2101.
3. "Bridge Geometry (RDS)," Michigan Department of State Highway and Transportation, Report Index 2702.

The abstracts of the three top candidate geometry programs are provided in Appendix I. The abstract for 'RDS' is admittedly brief due to the brief documentation submitted by Michigan. However, the authors know substantial user documentation exists and raised the documentation evaluation to satisfactory (S). Although "RDS" is applicable and is utilized for bridge geometry calculations as the rating would indicate, the program is large (large number of statements) and includes design features for roadway and bridge design. The authors believe that time and cost limitations prevent an in-depth study of "RDS". In addition, a large difference exists in the overall rating percentage between "RDS" and the next highest rated program (58% vs. 74%). Therefore, only candidate programs 1. and 2. above are intended to be reviewed in-depth during Phase II of the subject study.

2.7 COMPONENT SELECTION - PIERS

Documentation for forty-five pier and support structure programs was received in response to the initial mailing to state and provincial agencies. The documentation was entirely user documentation with 31% of the documentation again classified as minimal. In many instances, the documentation was only a few pages of output obtained from the program. Upon reviewing the provided documentation, it was discovered that many of the programs were specialized in areas such as footing design, cap design, column design, retaining wall design, and

TABLE 13. SUMMARY CRITERIA COMPARISON FOR CANDIDATE PROGRAMS FOR GEOMETRY

CRITERIA	CANDIDATE PROGRAMS		
	Index Number 1301	Index Number 2101	Index Number 2702
CRITERIA: The application programs selected must be as general as possible with respect to overall application capability. EVALUATION: Overall rating score.	Rating of 82/100	Rating of 74/100	Rating of 58/100
CRITERIA: The application programs selected must be adequately documented. EVALUATION: SATISFACTORY OR UNSATISFACTORY	Satisfactory	Satisfactory	Satisfactory
CRITERIA: The application program should be written in FORTRAN and be constructed with the greatest modularity in order to readily accomodate code changes, upgrades and different I/O requirements. EVALUATION: FORTRAN, MODULAR	FORTRAN Somewhat modular	FORTRAN Somewhat modular	FORTRAN Somewhat modular
CRITERIA: The system must be production oriented and utilize current AASHTO specifications. EVALUATION: PRODUCTION, CURRENT CODE	IN PRODUCTION USE. NOT CODE DEPENDENT	IN PRODUCTION USE. NOT CODE DEPENDENT	IN PRODUCTION USE. NOT CODE DEPENDENT
CRITERIA: The system should include the most adaptable methodology. EVALUATION: SATISFACTORY OR UNSATISFACTORY	SATISFACTORY	SATISFACTORY	SATISFACTORY

analysis. Few programs contained more than one or two of the above areas and even fewer had been updated to the 1977 AASHTO specifications. An in-depth study of the documentation in the various areas produced 146 global feature requirements to be queried in the questionnaire and used for evaluating the various programs. These features were obtained by taking the union of the primary features of the programs in each of the areas such as footing design, column design, etc. The global features and definitions are listed in the substructure portion of the questionnaire in Appendix F.

2.7.1 Piers Questionnaire Response

Thirty-two state and provincial agencies and twenty-five private consultants responded to the bridge substructure portion of the questionnaire. An evaluation of the responses as presented in Tables G-16 to G-20 of Appendix G indicated that approximately 47% of bridge substructure applications were automated. The state and provincial agencies indicated that they performed only approximately 35% of their substructure work using computers. This low percentage is attributed solely to the low quality of much of the available software as evidenced by the documentation. For instance, many of the programs are severely limited in the analysis area due to using either the slope deflection or moment distribution methods for the analysis portions of the programs.

Of the 146 global feature requirements established for program evaluations, the responses using the rating scheme of Section 2.4 produced the following results:

1) 36 (25%) of the global requirements were major mandatory (M+),
2) 81 (55%) of the global requirements were mandatory (M),
3) 29 (20%) of the global requirements were desirable (D), and
4) 0 (0%) of the global requirements were not required.

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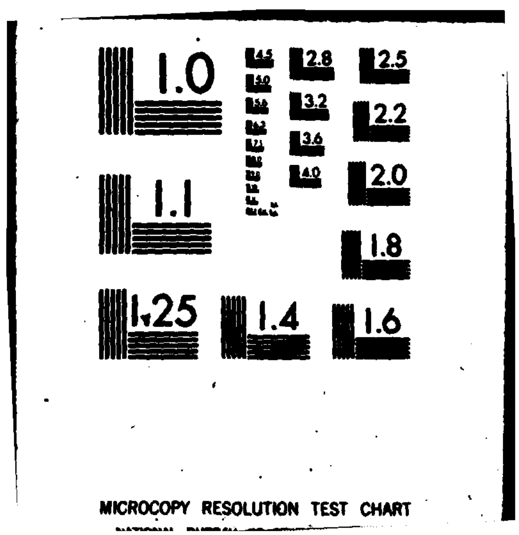
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MICROCOPY RESOLUTION TEST CHART

The specific items to each category above are summarized in Tables G-16 to G-20 of Appendix G along with an indication of the evaluation (Feature Status) of each requirement. The fact that 80% of the global features were thought to be mandatory or major mandatory by the respondees indicates that many of the agencies would increase their level of automation in the bridge substructure area if provided with more general and state-of-the-art programs. The high percentage, 80%, of mandatory and major mandatory features also indicates that the previously determined global features provide an applicable set of criteria to be used in evaluating the capabilities of each program.

2.7.2 Review of Available Substructure Software

Each of the forty-five geometry programs was evaluated using the previously established global feature requirements. The results of the extensive evaluation for each program are presented by program index numbers in Tables D-1 to D-9 of Appendix D.

A cross reference of the index numbers, program sources and agencies is presented in Table A-4 of Appendix A. Based on the ability of the program to satisfy the designated feature status, a point value was assigned as discussed in Section 2.4 for each feature that the program was able to satisfy according to the provided documentation. The substructure feature evaluations were then summarized in seventeen categories in the analysis, loading, design data, and design detail areas. The point values assigned to each program in each of the seventeen categories are presented in Table D-10 of Appendix D. The seventeen categories are indicated along the top portion of Table D-10. The total points and percentage of total points are summarized in Table D-11. In addition, the program usage and quality of the provided documentation are presented in Table D-11 for each of the programs. The five programs with the highest point values and adequate (S) user documentation are summarized in Table 14.

TABLE 14. SUMMARY OF SUBSTRUCTURE PROGRAM USAGE AND RATING

INDEX NO.	CALL NAME	PROGRAM USAGE: NUMBER ORGANIZATIONS		PROGRAM USAGE: NUMBER STAFF		DOCUMENTATION	RATING OF FEATURES						COMMENTS
		LIGHT USAGE	HEAVY USAGE	LIGHT USAGE	HEAVY USAGE		ANALYSIS	LOADINGS	DESIGN DATA	DESIGN DETAILS	OVERALL TOTAL RATING	OVERALL RATING BASED ON 100%	
2702		0	2	0	*	S	29	0	12	9	50	25	
2704		0	0	0	0	S	21	0	12	17	50	25	
2614	BR119	0	0	0	0	M	45	2	0	0	47	23	
1303		1	3	6	*	S	34	1	0	7	42	21	
CE	CE	0	0	0	0	S	43	0	0	0	43	21	
POSSIBLE							96	24	48	36	204	100	

*N.A. - Responding state did not specify number of staff

The program capabilities indicated in Tables D-1 to D-9 were initially determined from the documentation provided in response to the initial mailing. The results of the initial evaluation were then enclosed in the questionnaire booklet and mailed to the state that provided the program documentation. The changes, if any, made by the responding state or provincial agencies were then incorporated in the evaluation presented in Tables D-1 to D-9. For Tables D-3 to D-9, the feature status obtained from the questionnaire responses for each requirement are indicated at the bottom of the tables.

The fact that the highest rated program in the substructure area received a rating of only 25% indicates the seriousness of the software deficiencies in this area. A review of the evaluations under the seventeen categories of Table D-10 reinforces the causes for the deficiencies as stated in Section 2.3.2 as being due to the lack of generality and to the fact that many substructure programs are ten or fifteen years old. Many of the programs do not even account for all the loadings required by the '77 or earlier codes. Some of the programs have satisfactory analysis capabilities but are specialized for only components of the structure such as footings or caps. Also, few of the programs couple design and analysis features in the same program. After this evaluation, it is certainly not difficult to understand why only 47% of the substructure design is automated - deficiencies in the software.

2.7.3 Substructure Application Candidates and Description

The combination of the low overall ratings, the lack of generality, and the lack of incorporation of the state-of-the-art analysis and design capabilities prevent any of the programs reviewed from satisfying the selection criteria of Section 2.4. In view of the failure of the reviewed programs to satisfy this criteria, a second criteria will be used. This criteria is based on the functional modules to be delivered as stated in Task IIb, page 4-23, of the study proposal (Refer

ence 2). In the substructure application area of Task IIb, the module to be provided was to perform "the design and analysis of generalized two or three dimensional concrete frame piers."

Due to time and cost limitations, only three of the top five programs of Table 14 will be reviewed in-depth in Phase II of the study for possible selection in order to satisfy the second criteria. One of the omitted programs was specialized for abutments and footings (Index No. 2704) and did not satisfy the criteria. The three programs to be reviewed are:

1. "Pier Design", Michigan Department of Transportation, Report Index number 2702.
2. "The Analysis of Multiple Column Piers for Highway Bridges," Georgia Department of Transportation, Report Index number 1303.
3. "Pier Design for Bridges", Erdman and Anthony, Century Engineering, Inc., Report Index number CE.

The abstracts of the above three candidate programs are provided in Appendix I. The final selection will be based on the ability of the program to satisfy the second set of criteria as well as the modularity of the program. Since the substructure area is an obvious target for future enhancements beyond Phase II of the study, the modularity is an important consideration. In fact, capabilities may need to be sacrificed in favor of modularity so that the future enhancements necessitated by code requirement changes or user needs will not greatly impact the existing capabilities, or require a total rewrite of the module.

2.8 COMPONENT SELECTION - PILES

The pile foundation analysis/design components (or modules) which are recommended for inclusion into the integrated bridge design system are given herein. A total of 9 pile group foundation programs were reviewed, with no program actually performing the design task. A tabular summary of each system reviewed is given here, along with a more detailed discussion of the candidate pile foundation programs.

2.8.1 Piles Questionnaire Response

That portion of the questionnaire which pertained to pile group analysis requested information relative to both those features desired in a pile system and to the specific methods of analysis utilized in practice. This was done because it was realized from the outset that the methodology currently used to analyze pile groups differ widely among designers (sometimes even within the same design office). Results from this portion of the questionnaire indicated that users continue to prefer the flexure method (72.4% - see Table G-23). This preference is particularly unfortunate because the method does not yield satisfactory results when large lateral forces are present. Indeed, the method is decidely unconservative under a general loading condition generally encountered in the design of pier or bent type foundations. Such a condition results in an inbalance of forces either horizontally or vertically depending upon the assumption on how the lateral forces are distributed.

A further analysis of the data obtained from the questionnaires indicates that users prefer a method that can account for a layered soil (41.4% and 55.2% specified for Major Mandatory and Mandatory, respectively), various boundary conditions at the ends of the pile (top fixed - 73.3%, top pinned - 51.7%, bottom fixed - 62.1% and bottom pinned - 48.3%) and most importantly, lateral loadings in two directions (80.6%). In addition, a very high percentage of the users specified that the induced shears (76.7%) and bending moments (73.3%) within the pile were required. Finally, an array of general capabilities were specified as Major Mandatory by the users with 84% requiring bearing piles, 69% friction piles, and 53% required piles of different lengths. <u>All of these features are inconsistent with the assumptions regarding the flexure method.</u>

A review of the responses given for the pile group method of analysis (Table G-23) indicates that not only is the flexure formula the most preferred and familiar analysis technique, but

also that there is a general reluctance to replacing the approach with an imperical method. Indeed, only 25% (Table G-4) of the design function is automated, and little effort exists (Table G-5) for program development and support for pile foundation software. This is unfortunate in that the number of engineers and technicians engaged in pile foundation design (854) is nearly equal to the number engaged in the superstructure design function (883, Table C-3).

As a result of the analysis/design requirements specified in the questionnaire and from the experience of the authors, it was necessary to raise the feature status of the 3-D stiffness method from Desired to Major Mandatory (Table G-23). This method is able to consider completely general loading conditions as well as account for various degrees of pile fixity, soil interaction, etc. (See Exhibit F-1 of Appendix F, Nomenclature and Definition of Terms)

2.8.2 <u>Review of Available Software</u>

A total of 9 pile group programs were reviewed with respect to 80 features, resulting in an overall average rating of 41%. Programs with an above average overall rating were chosen as candidate programs. This resulted in the selection of four candidates, none of which utilized the flexure formula. These programs were then reviewed with respect to the five item criteria discussed in Section 2.4, to determine which programs were amenable for general usage and implementation into an integrated bridge design system.

In order to gain insight into the basis for program selection or rejection, the reader is directed to review Appendix E and Table 15 for a comparison of application features available within each program, and the abstracts (presented in Appendix I) which describe each candidate program in some detail. Also, in order to provide a terse explanation of the status of each candidate program with respect to the criteria, the following is offered:

TABLE 15. SUMMARY CRITERIA COMPARISON FOR CANDIDATE PROGRAMS - PILE GROUP FOUNDATIONS

CRITERIA	APPLICATION PROGRAMS			
	4501 (ONTARIO)	5607 (TEXAS)	2306 (MAINE)	2502 (MARYLAND)
CRITERIA: The application programs selected must be as general as possible with respect to overall application compability. **EVALUATION:** Overall rating score.	55	57	60	79
CRITERIA: The application programs selected must be adequately documented. **EVALUATION:** Satisfactory or unsatisfactory.	S	S	S	S
CRITERIA: The application program should be written in FORTRAN and be constructed with the greatest modularity in order to readily accomodate code changes, upgrades and different I/O requirements. **EVALUATION:** FORTRAN, MODULAR	FOR MOD	FOR MOD	FOR (POL) MOD	FOR MOD
CRITERIA: The system must be production oriented and utilize current AASHTO specifications. **EVALUATION:** PRODUCTION, CURRENT CODE	P CC	- CC	P CC	P CC
CRITERIA: The system should include the most adaptable methodology. **EVALUATION:** SATISFACTORY	U	S	S	S

TABLE 15. RATING SUMMARY FOR PILE GROUP FOUNDATION DESIGN PROGRAMS

Index No.	Call Name	GENERAL LIMITATIONS				OPTIONS AND CAPABILITIES				DESIGN/ANALYSIS	
		SIZE LIMITATIONS	PILE SECTIONS	MATERIAL TYPES	GENERAL CONFIGURATIONS	PILE END RESTRAINTS	LOADS	REACTIONS AND DISPLACEMENTS	GENERAL CAPABILITIES	CAPABILITIES	METHODS *
1301			7	6	0	0	10	1	0	0	12
1504			7	6	1	0	10	0	0	0	12
2306	PILGR.76.1		9	12	1	0	12	12	6	7	12
2502	PGA 76.01		9	12	12	9	12	12	6	7	12
3609	P 20-100		7	4	0	0	4	0	0	0	3
3610	P 20-204		7	4	0	0	4	1	0	0	6
4501	BR00610		9	12	8	0	4	10	3	10	6
4602			1	4	4	0	4	0	0	0	3
5607	Group		9	12	11	9	4	4	6	7	6

* Score is based upon the ranking that the program's methodology attained, i.e., a program which employs an M^{+} methodology receives a 12 in this category.

TABLE 15. OVERALL RATING FOR PILE GROUP FOUNDATION DESIGN PROGRAMS

INDEX NO.	CALL NAME	PROGRAM USAGE				DOCUMENTATION PROVIDED	TOTAL RATING OF FEATURES					COMMENTS
		NUMBER OF ORGANIZATIONS		NUMBER OF STAFF								
		LIGHT USAGE	HEAVY USAGE	LIGHT USAGE	HEAVY USAGE		GENERAL LIMITATIONS	OPTIONS AND CAPABILITIES	DESIGN/ANALYSIS	TOTAL OVERALL PROGRAM RATING	OVERALL RATING BASED ON 100%	
1301						S	13	11	12	36	33	
1504						U	14	10	12	36	33	
2306	PILGR 76.1B					S	22	24	19	65	60	CANDIDATE
2502	PGA 76.01					S	33	33	19	85	79	CANDIDATE
3609	P 20-100					U	11	4	3	18	17	
3610	P 20-204					U	11	5	6	22	20	
4501	BROO610					S	29	14	16	59	55	CANDIDATE
4502						S	9	4	3	16	15	
5607	GROUP					S	32	17	13	62	57	CANDIDATE

BRIDGE PILE GROUP FOUNDATION DESIGN PROGRAMS

4501 - Pile Group Analysis (Ontario)

Ontario's program for pile foundation analysis and design employs the elastic center analysis method, a technique that is more satisfactory than the genral flexure method. Additionally, the system is modularly constructed and utilizes current AASHTO code provisions. However, the elastic center method is unsatisfactory in light of the requirements specified within the questionnaire response. For this reason, this system is not a recommended program.

5607 - Analysis of Foundations with Widely Spaced Batter Piles (Texas)

This system is not recommended for inclusion into the integrated system as it considers only a two-dimensional pile group and is not a production program. However, it is felt that the excellent program features which consider non-linear pile and soil behavior justify future consideration for implementation.

2306 - The Analysis of Pile Group Footings (Maine)

This system utilizes a three-dimensional stiffness analysis technique, is modular in construction, and utilizes current code. A review of Appendix E indicates a good degree of generality in capabilities. For these reasons, this system has been designated a recommended program.

2502 - The Analysis of Pile Group Foundations (Maryland)

This system received the highest overall ranking (85 or 79% of the features reviewed) of all pile programs considered. It utilizes a general three-dimensional stiffness analysis technique, is extremely modular in construction, and employs current AASHTO code. Moreover, numerous analysis options give this system a high degree of generality. For these reasons, this system is designated as a recommended program.

2.8.3 Piles Application Candidates and Description

Thus, it is seen that the systems which are most satisfactory for design of bridge pile bents and pile group foundations are the analysis of Pile Group Foundations from Maryland (79%) and the analysis of Pile Group Foundations from Maine. Although neither system is truly a design program, both do utilize the very general stiffness matrix analysis technique. It is felt that from these a generalized subsystem for analysis and design of bridge pile group foundations can be developed.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Schelling, David R
Survey of bridge-oriented design software / by David R. Schelling, Department of Civil Engineering, University of Maryland, College Park, Md. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
xii, 92 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; K-80-1)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-78-M-5127.
A CASE report under the Computer-Aided Structural Engineering Project.
References: p. 92.

1. Bridge design. 2. Computer-aided design. 3. Computer-Aided Structural Engineering Project. 4. Computer programs. 5. Computer systems programs. 6. Highway bridges. I. Maryland. University. Dept. of Civil Engineering. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; K-80-1.
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